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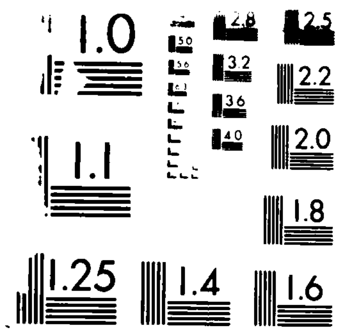
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Resilient Modulus of Freeze-Thaw Affected Granular Soils for Pavement Design and Evaluation

Part 2. Field Validation Tests at Winchendon, Massachusetts, Test Sections

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16. Abstract
Stress-deformation data for six granular soils ranging from sandy silt to dense-graded crushed stone were obtained from in-situ tests and laboratory tests. Surface deflections were measured in the in-situ tests, with repeated-load plate-bearing and falling-weight deflectometer equipment, when the six granular soils were frozen, thawed, and at various stages of recovery from thaw weakening. The measured deflections were used to judge the validity of procedures developed for laboratory triaxial tests to determine nonlinear resilient moduli of specimens in the frozen, thawed, and recovering states. The validity of the nonlinear resilient moduli, expressed as functions of externally applied stress and moisture tension, was confirmed by using the expressions to calculate surface deflections that were found to compare well with deflections measured in the in-situ tests. The tests on specimens at various stages of recovery are especially significant because they show a strong dependence of the resilient modulus on moisture tension, leading to the conclusion that predictions or in-situ measurements of moisture tension can be used to evaluate expected seasonal variation in the resilient modulus of granular soils.

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PREFACE

This report was prepared by Thaddeus C. Johnson and Diane L. Bentley, Research Civil Engineers, Civil Engineering Research Branch; and David M. Cole, Research Civil Engineer, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The study was funded under DA Project 4A762730AT42, *Design, Construction and Operations Technology for Cold Regions*; Task BS, *Base Support*; Work Unit 002, *Seasonal Change in Strength and Stiffness of Soils and Base Courses.* The Federal Highway Administration (FHWA) and the Federal Aviation Administration (FAA) of the Department of Transportation shared equally in the funding, under FHWA Order No. 8-3-0187, *Full-scale Field Tests to Evaluate Frost Action Predictive Techniques.*

The authors gratefully acknowledge the financial support of the Corps of Engineers, the FHWA and the FAA. The Massachusetts Department of Public Works made available their frost action test site at Winchendon, Massachusetts. The authors were allowed virtually unrestricted use of the site for field testing and data collection, and the Department also provided extensive data on soil properties and other site conditions. Dr. Richard Berg was co-leader of the overall project, along with the senior author, and provided essential field and laboratory data from other phases of the work. Many other persons at CRREL contributed to the study. One of the principal contributors to the work described in this report was Dr. Lynne Irwin, who, while on temporary assignment at CRREL during sabbatical leave from Cornell University, developed NELAPAV, the computer program used in the deflection basin analyses. Other principal contributors were Edwin Chamberlain, who had a major role in the development of the laboratory testing techniques; Glenn Durell, who conducted the resilient modulus testing; and Donald Keller, who conducted the field loading tests. David Carbee, Gregor Fellers, and Jonathan Ingersoll also assisted in the research. This report was technically reviewed by F.H. Sayles of CRREL.

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Resilient Modulus of Freeze-Thaw Affected Granular Soils for Pavement Design and Evaluation

Part 2: Field Validation Tests at Winchendon, Massachusetts, Test Sections

T.C. JOHNSON, D.L. BENTLEY AND D.M. COLE

INTRODUCTION

The damaging effects of the freeze-thaw cycle on the riding qualities, integrity, and durability of pavements are notorious. In areas of seasonal frost the supporting capacity of subgrade soils and unbound base and subbase materials for roads and airfields can vary drastically through freeze-thaw cycles and the subsequent spring-summer recovery period. In a joint project with the Federal Highway Administration and the Federal Aviation Administration, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) has evaluated these fluctuations in material properties for six test soils and developed suitable predictive models. Both laboratory and field tests were conducted.

This report focuses on the underlying cause of problems of premature distress in pavement systems that are susceptible to frost—the reduction of the resilient modulus of subgrade soils and unbound base courses during and following spring thaws. In this context the resilient modulus is conventionally defined as deviator stress divided by resilient—i.e., recoverable—strain. The research results presented in the report are concerned with frost-susceptible granular soils that exhibit little or no cohesion and a high degree of nonlinearity. The research objective was to develop laboratory methods of characterizing the seasonal changes of the resilient modulus of these soils throughout a complete annual cycle. It was considered necessary to conduct field tests to validate the laboratory methods. The field tests and analysis of the data are the subject of this report.

Repeated-load triaxial tests were performed to determine the resilient characteristics of the component materials in experimental paved test sections under conditions simulating those that prevailed during the field tests. The laboratory triaxial tests were performed on soils in the frozen, thawed, recovering, and recovered conditions. Empirical relationships were then generated by standard statistical techniques to express the resilient modulus M_r as a function of density, soil moisture tension, and the stresses imposed in the triaxial tests. For frozen soil and for asphalt concrete the temperature is also a key parameter.

Field tests were used to determine the surface deflection response of paved soil test sections under plate loads. Surface deflection basins were measured under loads imposed by a repeated-load plate-bearing (RPB) apparatus and a falling-weight deflectometer (FWD). The tests were performed at critical times between late fall and late spring to characterize the variation in load response throughout the freeze-thaw-recovery cycle.

The validity of the laboratory results was then examined by comparing the measured deflection basins with deflection basins calculated for the test section using the expressions for resilient modulus developed from the laboratory tests. In using these expressions, temperatures and moisture tensions measured at the time of each field loading test were applied to evaluate the resilient modulus. Layered elastic analyses of the test sections under the conditions prevailing during each field loading test yielded stresses, strains, and resilient vertical displacements throughout the system; calculated surface deflection basins were thus generated and compared to the deflection basins actually measured in the field.

The field and laboratory tests were conducted on six soils in test sections constructed by the Massachusetts Department of Public Works in Winchendon, Massachusetts. The results for the six soils are presented here. Detailed procedures, results, and analyses of repeated-load triaxial tests to characterize the asphalt concrete pavement, the six test soils, and the natural sandy gravel subgrade are given by Cole et al. (1986).

SAMPLING OF TEST SECTION

The Winchendon test site, constructed in 1978 by the Massachusetts Department of Public Works, consists of 24 soil test sections (Figs. 1, 2). Twelve different soils are used, each in embankments of two different heights. Six of the higher embankments were used as test sections in this research, each consisting of about 50–90 mm of asphalt concrete and 1.5 m of test soil (either Ikalanian sand, Graves sand, Hart Brothers sand, Hyannis sand, dense-graded stone, or Sibley till) overlying the natural subgrade, a clean gravelly sand (Fig. 3). The water table is about 1.4 m below the pavement surface.

Samples of the asphalt concrete, the test soils, and the natural subgrade were taken in October 1978, before freezing had occurred. Core samples 101.6 mm in diameter were taken from the asphalt pavement. Undisturbed samples of the test soils, except the dense-graded stone, were taken with a double-tube auger. Soil samples were 57.2 mm in diameter and 152.4 mm long. They were preserved in the split sleeves used in the sampling device, wrapped in polyethylene film to prevent moisture loss, and padded to prevent disturbance during transportation. Bag samples of the natural subgrade material and the test soils were also obtained.

In February 1979, once frost penetration was sufficient, undisturbed samples of frozen soil were taken from the Ikalanian sand, Graves sand, Hart Brothers sand, and Hyannis sand test sections. A single-tube, hollow auger was used. Cores 50.8 mm in diameter and up to 300 mm long were obtained. The Sibley till and dense-graded stone could not be core-drilled because of the presence of many stones. Occasional pebbles in the other sections also caused difficulties. All the core samples were tightly wrapped in polyethylene film and placed in bags with snow to prevent sublimation during transport to the laboratory. The cores were stored in a -7°C environment until trimmed and tested.

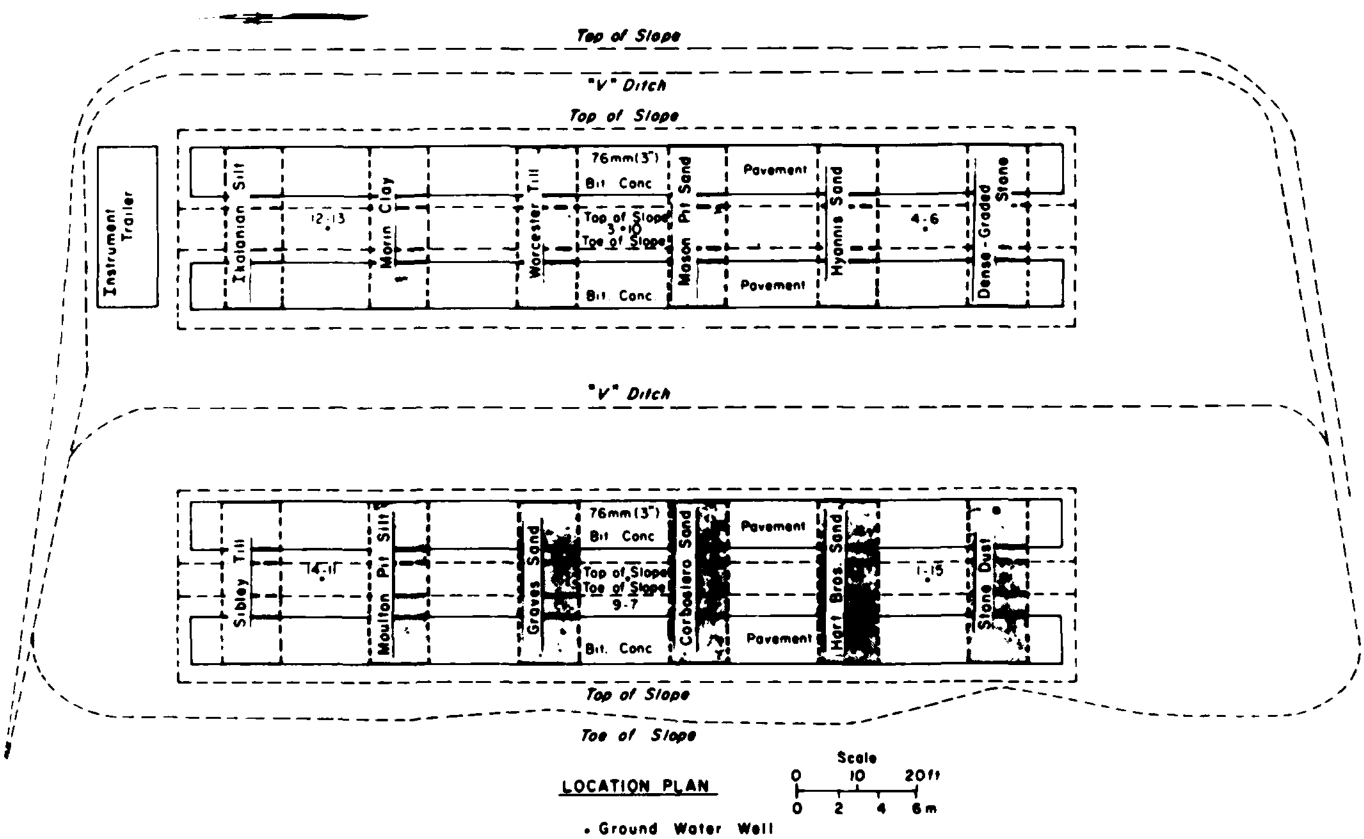


Figure 1. Plan view, Winchendon, Mass., test site.

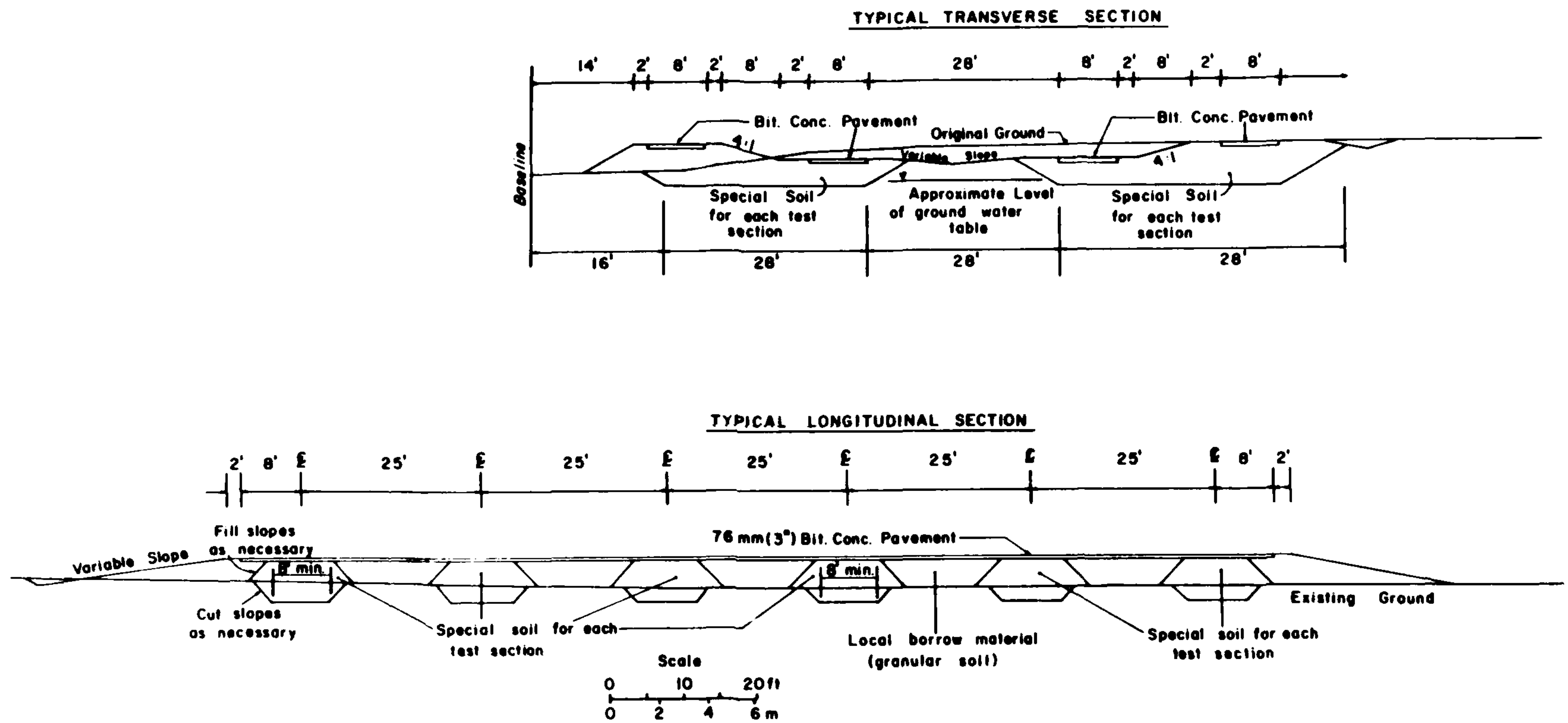


Figure 2. Transverse and longitudinal sections, Winchendon test site.

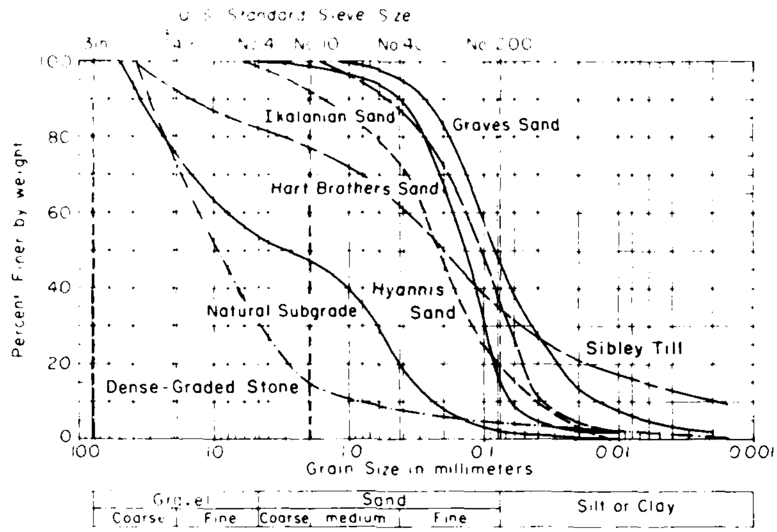


Figure 3. Grain-size distributions of test soils and natural subgrade.

LABORATORY TESTS

Laboratory tests were performed to characterize the resilient modulus of the asphalt concrete, the six test soils, and the natural subgrade soil. Detailed test procedures and data analysis are given by Cole et al. (1986). The tests are briefly described here, and the results are summarized, only to the extent necessary to give meaning to the field testing and analyses conducted to validate the laboratory results.

Asphalt concrete

Initially, asphalt concrete core specimens 101.6 mm in diameter were tested in repeated indirect tension (diametral compression) at two load durations (0.1 and 1.0 sec) and at temperatures from -10 to +32°F. Cores 50 to 90 mm in length also were cemented together with asphalt emulsion in groups of three to form cylindrical specimens 200-250 mm long and were tested in repeated-load unconfined compression at axial stresses from 69.0 to 241.3 kPa and temperatures from -10 to +39°C. It was desired to simulate the load pulse of each of the two dynamic plate-loading tests used in the field in-situ tests, the RPB and the FWD, so three loading waveforms were used in the laboratory: a 1-sec pulse applied every 3 seconds, which simulates the RPB pulse; a continuous haversine waveform at 1, 4, and 16 Hz according to ASTM D3497-76T; and a 28-ms haversine pulse every 2 seconds that simulates the FWD load pulse.

Multiple linear regression analyses of the results showed that the asphalt concrete resilient modulus M_r is insensitive to the peak amplitude of the stress. For the slower RPB waveform, M_r is a function of the temperature only, while for haversine loading M_r is a function of temperature and frequency (Table 1). Representative results showing relationships generated by the regression equations are given in Figure 4.

Natural subgrade material

Since the natural gravelly sand subgrade soil existing beneath the test sections at Winchendon does not undergo freezing and thawing, it was tested only in the nonfrozen condition. Specimens measuring 152.4 mm in diameter and 381.0 mm long were compacted to about 2.00 mg/m³, the estimated in-situ dry density. Once placed in a triaxial cell, each specimen was vacuum-saturated and then subjected to various combinations of static axial and confining stresses as given in Table 2. Drainage was permitted each time the static stress level was increased, though the reservoir level was maintained at the top of the sample. A deviator stress was then applied repeatedly under the waveforms of the RPB and FWD load pulses, while permitting no further drainage.

A stepwise multiple linear regression analysis was performed on the results. The resilient modulus was expressed as a function of either of two stress invariant parameters. Initially the bulk stress, θ, or first stress invariant $J_1 = \sigma_1 + \sigma_2 + \sigma_3$ was used, in accordance with conventional prac-

Table 1. Results of regression analysis.

Material	*Load pulse*	*Regression equation*	*n*	R^2	*Std. error*	*Eq. no.*
Asphalt concrete						
	RPB	$M_r(\mathrm{MPa}) = \exp[9.204 - 5.552 \times 10^{-2} T - 9.744 \times 10^{-4} T^2]$	85	0.97	0.287	1
	Haversine	$M_r(\mathrm{MPa}) = \exp[9.183 - 7.47 \times 10^{-2} T]\, \mathrm{f}^{0.1777}$	158	0.81	0.469	2
	FWD	$M_r(\mathrm{MPa}) = \exp[9.429 - 7.47 \times 10^{-2} T]$	—	—	—	3
Natural subgrade						
	RPB and FWD	$M_r(\mathrm{MPa}) = 8.829\, f_1(\sigma)^{0.708}$	65	0.67	0.235	4
	RPB and FWD	$M_r(\mathrm{MPa}) = 20.74\, f_2(\sigma)^{0.352}$	65	0.76	0.201	5
Graves sand						
Frozen	RPB	$M_r(\mathrm{MPa}) = \exp(9.677 - 1.0314T - 0.0708T^2)(\tau_{oct}/\sigma_o)^{-0.682}$	56	0.88	0.332	7
	RPB	$M_r(\mathrm{MPa}) = 39.1(w_u/w_t)^{-1.79}$	95	0.91	0.502	8
	FWD	$M_r(\mathrm{MPa}) = 32.14(w_u/w_t)^{-1.96}$	73	0.95	0.446	9
Thawed	RPB	$M_r(\mathrm{MPa}) = 2.139 \times 10^6\, f(\psi)^{-2.7925}\, f_1(\sigma)^{0.462}$	186	0.76	0.209	10
	FWD	$M_r(\mathrm{MPa}) = 9.27 \times 10^5\, f(\psi)^{-2.60}\, f_1(\sigma)^{0.477}$	222	0.71	0.224	11
	RPB	$M_r(\mathrm{MPa}) = 6.68 \times 10^4\, f(\psi)^{-2.2948}\, f_2(\sigma)^{0.414}$	186	0.89	0.144	12
	FWD	$M_r(\mathrm{MPa}) = 1.47 \times 10^6\, f(\psi)^{-2.75}\, f_2(\sigma)^{0.413}$	222	0.86	0.157	13
Recovered	RPB	$M_r(\mathrm{MPa}) = 6.89\, f_1(\sigma)^{0.418}$	36	0.76	0.247	14
	RPB	$M_r(\mathrm{MPa}) = 4.80\, f_2(\sigma)^{0.4046}$	36	0.87	0.185	15
Ikalanian sand						
Frozen	RPB	$M_r(\mathrm{GPa}) = \exp[13.74 - (0.820)T - (0.0538)T^2 - (0.8378)w + (0.04416)w^2](\tau_{oct}/\sigma_o)^{-0.382}$	62	0.90	0.308	16
	RPB	$M_r(\mathrm{MPa}) = 86.4(w_u/w_t)^{-1.32}$	87	0.92	0.749	17
Thawed	RPB	$M_r(\mathrm{MPa}) = 8.129 \times 10^4\, f(\psi)^{-3.324}\, f(\gamma)^{11.578}\, f_1(\sigma)^{0.490}$	119	0.84	0.323	18
	RPB	$M_r(\mathrm{MPa}) = 3.021 \times 10^4\, f(\psi)^{-3.266}\, f(\gamma)^{11.634}\, f_2(\sigma)^{0.442}$	119	0.89	0.276	19
Recovered	RPB	$M_r(\mathrm{MPa}) = 5.69 \times 10^6\, f(\psi)^{-3.118}\, f_1(\sigma)^{0.537}$	38	0.88	0.205	20
	RPB	$M_r(\mathrm{MPa}) = 2.405 \times 10^4\, f(\psi)^{-2.918}\, f_2(\sigma)^{0.442}$	38	0.84	0.238	21
Hart Brothers sand						
Frozen	FWD	$M_r(\mathrm{MPa}) = 38.28(w_u/w_t)^{-1.782}$	88	0.95	0.53	22
	RPB	$M_r(\mathrm{MPa}) = 4.085 \times 10^1\, (w_u/w_t)^{-1.59}$	99	0.92	0.623	22
	FWD	$M_r(\mathrm{MPa}) = 8.05 \times 10^{-2}\, f(\gamma_d)^{7.64}\, f_2(\sigma)^{0.365}\, (w_u/w_t)^{-1.97}$	88	0.97	0.445	23
	FWD	$M_r(\mathrm{MPa}) = 4.689 \times 10^{-1}\, f_1(\sigma)^{0.484}\, (w_u/w_t)^{-1.38}$	88	0.96	0.464	25
Thawed	RPB	$M_r(\mathrm{MPa}) = 2.97 \times 10^5\, f(\psi)^{-3.063}\, f(\gamma)^{5.986}\, f_2(\sigma)^{0.453}$	174	0.71	0.280	26
	RPB	$M_r(\mathrm{MPa}) = 1.269 \times 10^5\, f(\psi)^{-3.089}\, f(\gamma)^{7.023}\, f_2(\sigma)^{0.453}$	174	0.87	0.185	27
	FWD	$M_r(\mathrm{MPa}) = 3.93 \times 10^4\, f(\psi)^{-2.67}\, f(\gamma)^{6.18}\, f_1(\sigma)^{0.457}$	164	0.67	0.292	28
	FWD	$M_r(\mathrm{MPa}) = 3.81 \times 10^4\, f(\psi)^{-2.817}\, f(\gamma)^{7.43}\, f_2(\sigma)^{0.375}$	164	0.67	0.292	29
Hyannis sand						
Frozen	RPB	$M_r(\mathrm{MPa}) = 0.68\, f(\gamma)^{11.0}\, (w_u/w_t)^{-2.12}$	69	0.96	0.536	30
	RPB	$M_r(\mathrm{MPa}) = 33.45(w_u/w_t)^{-2.03}$	69	0.95	0.617	31
Thawed	FWD	$M_r(\mathrm{MPa}) = 7.147 \times 10^4\, f(\psi)^{-1.782}\, f_2(\sigma)^{0.264}$	128	0.71	0.129	32
	FWD	$M_r(\mathrm{MPa}) = 3.57 \times 10^7\, f(\psi)^{-3.276}\, f_1(\sigma)^{0.3628}$	61	0.74	0.194	33
Dense-graded stone						
Frozen	RPB	$M_r(\mathrm{MPa}) = 82.27(w_u/w_t)^{-2.03}$	32	0.97	0.413	34
Thawed	RPB	$M_r(\mathrm{MPa}) = 1.56 \times 10^5\, f(\psi)^{-1.76}\, f_2(\sigma)^{0.136}$	64	0.65	0.202	35
	RPB	$M_r(\mathrm{MPa}) = 7.17 \times 10^4\, f(\psi)^{-1.589}\, f_2(\sigma)^{0.1725}$	64	0.65	0.203	36
Sibley till						
Frozen	RPB	$M_r(\mathrm{MPa}) = 1.01 \times 10^2 (w_u/w_t)^{-3.446}$	108	0.87	0.71	37
Thawed	RPB	$M_r(\mathrm{MPa}) = 7.47 \times 10^6\, f(\psi)^{2.829}\, f_2(\sigma)^{0.192}$	118	0.63	0.283	38
	RPB	$M_r(\mathrm{MPa}) = 1.29 \times 10^7\, f(\psi)^{-2.84}$	118	0.54	0.313	39

NOTES:

RPB = repeated-plate bearing apparatus waveform
FWD = falling weight deflectometer waveform
n = number of points
M_r = resilient modulus
f = load wave frequency
$f_1(\sigma) = (J_1/\sigma_o)$
$f_2(\sigma) = [(J_1/\tau_{oct})/\sigma_o]$
σ_o = 1 kPa
w_u = unfrozen water content
w_t = total water content
$T = \theta/\theta_o$
θ_o = 1°C
$f(\psi) = [(101.38 - \psi)/\psi_o]$
ψ_o = 1 kPa
$f(\gamma) = \gamma/\gamma_o$
γ_o = 1 mg/m³

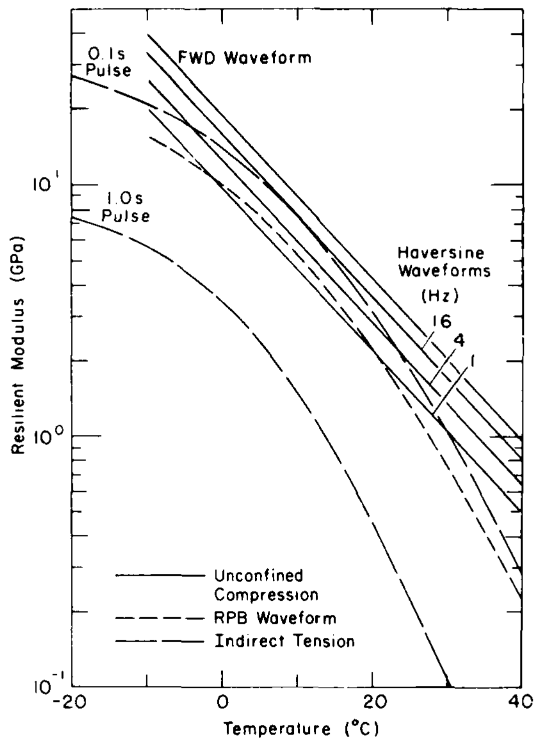


Figure 4. Resilient modulus of asphalt concrete vs temperature for various loading conditions.

tice for characterizing the nonlinear resilient modulus of granular soil. It was found, however, in tests on thawed test soil that M_r not only increased with J_1 but also tended to decrease somewhat with increasing principal stress ratio, an effect that was particularly evident when the minor principal stress σ_3 was held constant and the deviator stress $\sigma_d = \sigma_1 - \sigma_3$ was increased to a higher level. Another stress function, J_2/τ_{oct}, was selected to reflect the two different trends of variation of M_r with stress. The second stress invariant can be expressed as

$$J_2 = \sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1$$

but in triaxial tests with $\sigma_2 = \sigma_3$ and $\sigma_d = \sigma_1 - \sigma_3$, it follows that

$$J_2 = 3\sigma_3^2 + 2\sigma_3\sigma_d.$$

Similarly, the general form of the expression for the octahedral shear stress is

$$\tau_{oct} = \tfrac{1}{3}[(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2]^{1/2}$$

but in triaxial tests it is found that

$$\tau_{oct} = \sqrt{2/3}\,\sigma_d$$

and the selected invariant stress parameter can be expressed as

$$J_2/\tau_{oct} = \frac{9\sigma_3^2 + 6\sigma_3\sigma_d}{\sqrt{2}\,\sigma_d}$$

Because the data sets from the RPB and FWD load pulses indicated no statistically significant difference (Cole et al. 1981), the results were merged. The equations resulting from regression analyses are expressed in terms of the two selected invariant stress parameters (Table 1). It is noteworthy that the coefficient of determination (R^2)

Table 2. Applied stress levels.

Static axial stress, σ_1 (kPa)	*Static confining stress, σ_3 (kPa)*	*Cyclic axial* stress, σ_d (kPa)*	σ_1/σ_3
	a. Frozen specimens		
—	69	60	—
—	69	138	—
—	69	207	—
—	69	276	—
—	69	345	—
—	69	482	—
—	69	620	—
—	69	827	—
	b. Thawed and recovered specimens		
—	6.9	3.4	1.5
—	13.8	6.9	1.5
—	27.6	13.8	1.5
—	48.3	24.1	1.5
—	69.0	34.5	1.5
—	6.9	6.9	2.0
—	13.8	13.8	2.0
—	27.6	27.6	2.0
—	48.3	48.3	2.0
—	69.0	69.0	2.0
—	6.9	10.3	2.5
—	13.8	20.7	2.5
—	27.6	41.4	2.5
—	48.3	72.4	2.5
—	69.0	103.4	2.5
	c. Natural subgrade material		
13.8	5.5	3.4	—
27.6	11.0	6.9	—
55.2	22.1	13.8	—

* Deviator stress.

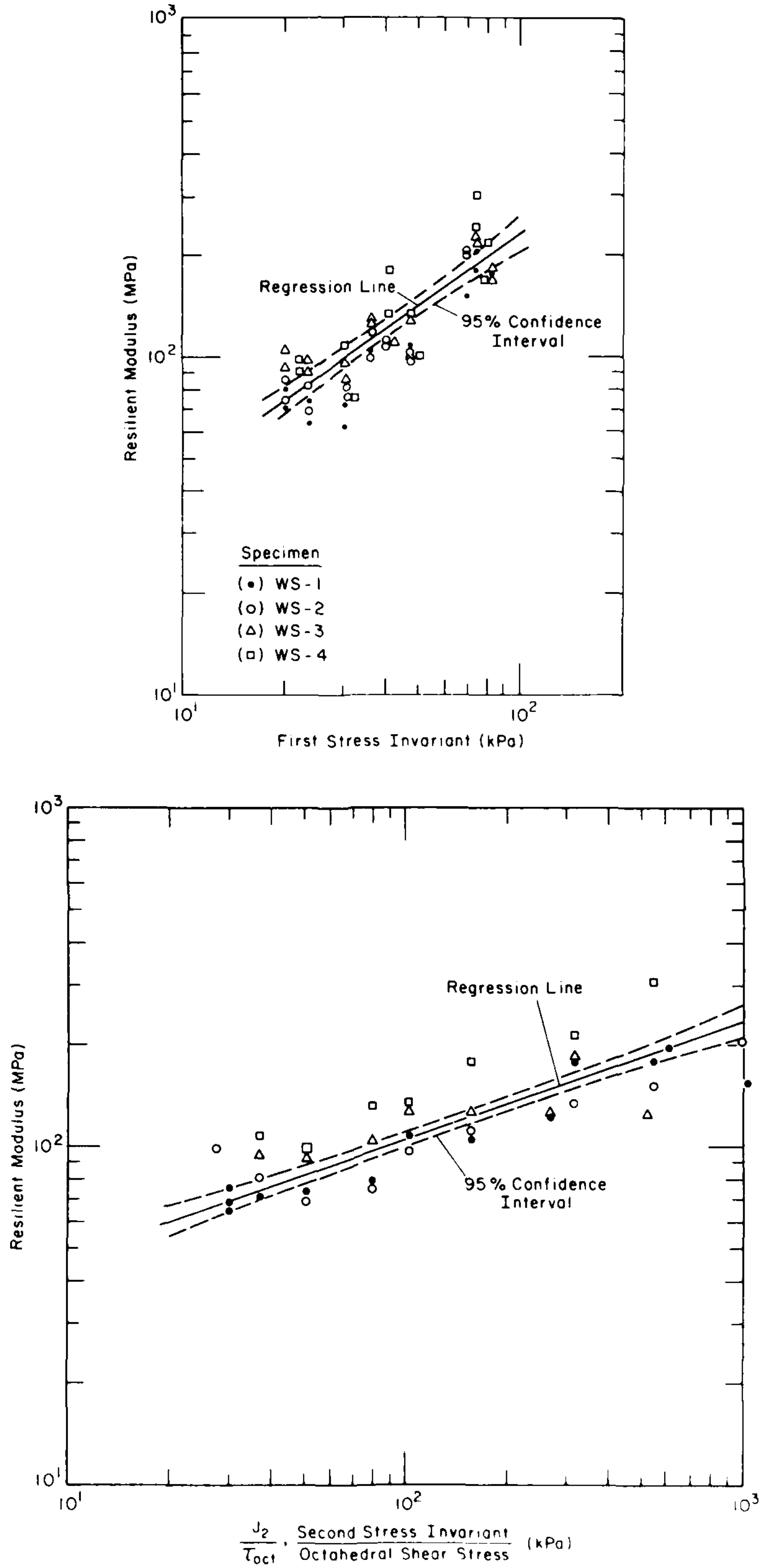


Figure 5. Resilient modulus vs invariant stress parameters for natural subgrade.

is somewhat higher for the equation in terms of J_2/τ_{oct}. The test data and regression lines are shown in Figure 5, with a 95% confidence interval.

Test soils

Each of the six test soils was subjected to repeated-load triaxial tests in the frozen, thawed, recovering, and recovered conditions. The term thawed can be used in two senses. Broadly construed, it means any soil that has been frozen and now exists at a temperature above 0°C. While the thaw front (0°C isotherm) is advancing into the ground or through a specimen, the soil is said to be thawing. With passage of the 0°C isotherm the soil just thawed begins to recover, a time-dependent process tnat starts with dissipation of pore pressure and consolidation and, for soils above the water table, progresses through a desaturation phase with build-up of moisture tension. The term "thawed" is used in this report to describe soil still undergoing the recovery process, but the term "recovering" is also used to refer to the period of consolidation and build-up of moisture tension. Recovery culminates in an equilibrium in which the state of stress in the pore water is affected only by external influences such as weather or the position of the ground water table. The term "recovered" is applied to the latter equilibrium condition, generally reached in the fall shortly before onset of another freezing cycle.

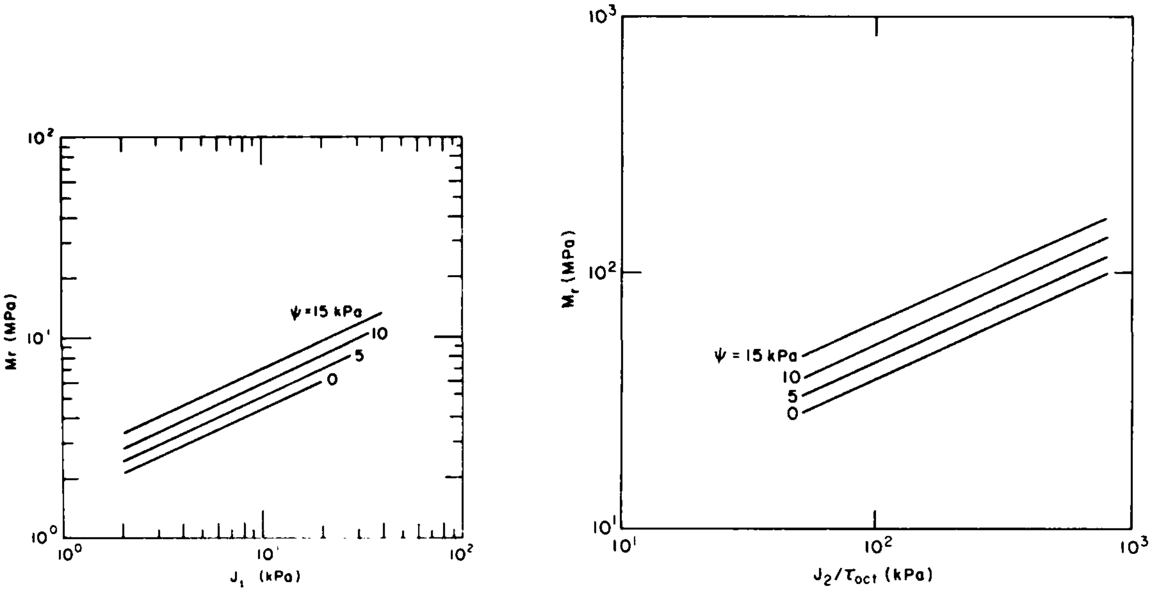
The triaxial tests were performed on a closed-loop electrohydraulic testing machine. Cores 50.8 or 57.2 mm in diameter, as noted above, were trimmed to a length of 127.0 mm (for the Hyannis, Ikalanian, Hart Brothers, and Graves sands) and tested in a triaxial cell. Remolded samples 152.4 mm in diameter were made from the Sibley till and dense-graded stone to test in a larger triaxial cell. The testing regime in all cases was to apply and maintain a constant confining pressure σ_3 and to apply repeatedly a deviator stress σ_d. The deviator stress pulse, either 1 sec on and 2 sec off (RPB pulse), or 28 ms on and 2 sec off (FWD pulse), was repeated 200 times at each stress level.

Specimen temperatures for tests in the frozen condition ranged from -0.2 to -10.0°C. Confining pressure was 69.0 kPa and deviator stresses ranged from 69 to 827 kPa. Once tested in the frozen state, each specimen was thawed in the triaxial device and retested repeatedly to characterize the thawed and recovering conditions. In each test the specimen was allowed to drain or come to equilibrium under the applied confining stress before the cyclic deviator stress was applied. After the first test in the thawed condition, gradual recovery was simulated by inducing successive step increases in moisture tension ψ, performing triaxial tests at each ψ level at a range in values of σ_3 and σ_d (Table 2). For this purpose the top cap of the specimen was removed and the specimen was air-dried to attain a somewhat higher level of moisture tension ψ. This procedure was repeated until the thawed specimen had been tested at three or more levels of ψ.

The results of multiple linear regression analysis of the data on the six test soils in the frozen, thawed (recovering), and in some cases the recovered conditions are given in Table 1. In the frozen state the significant variables are temperature, deviator stress, and in some cases total moisture content. Preferring invariant stress function for application to the field in-situ problem, we have expressed the stress function in terms of octahedral shear stress. For Hart Brothers sand, Hyannis sand, Sibley till, and dense-graded stone the validity of the equations was extended to the melting point (Cole 1984), and the moduli are expressed as a function of the unfrozen water contents.

In the thawed and recovering states the significant variables are a moisture tension parameter $f(\psi)$, which is atmospheric pressure minus the gauge value of soil moisture tension $(u_a-\psi)$, dry density γ_d, and a stress parameter, either J_1 or J_2/τ_{oct}. In some cases the use of J_2/τ_{oct} gave substantially higher values of R^2. It was intended that the field loading tests be analyzed using the expressions for resilient moduli in terms of J_2/τ_{oct} for all the soils, because this model correlated better in some cases with the laboratory data. However, due to an early problem with NELAPAV, the elastic layered analysis program developed for deflection basin analyses, the first analyses of field data were performed using nonlinear moduli expressed in terms of J_1. When the problem with NELAPAV was corrected, the deflection basins of the remaining test sections were analyzed using regression equations expressed in terms of J_2/τ_{oct}. Typical plots representing the dependency of the resilient modulus of thawed soil on either of the two invariant stress functions are given in Figure 6.

Samples of the test soils taken in the fall of 1978 were construed to reflect the fully recovered conditions; they were tested at the same stress levels as the thawed/recovering specimens but at only the level of ψ prevailing in-situ when the samples were taken. Regression analyses of the results (Table 1) showed that the stress parameter, J_1 or J_2/τ_{oct}, is a



a. Graves sand.

b. Hart Brothers sand.

Figure 6. Resilient modulus vs invariant stress parameters for two thawed test soils.

significant variable. In some cases ψ was accepted as a variable, while in other cases the range of ψ in the available data was small and did not meet the test for acceptance as statistically significant.

FIELD TESTS

Laboratory repeated-load triaxial testing of thawed soils requires special techniques that were under development as an objective of this project. Consequently it was essential to test the procedures and verify the moduli determined through their use. The method chosen to validate the procedures was to calculate surface deflection basins in experimental pavements with the aid of the laboratory-determined moduli and to compare these calculated basins with surface deflection basins observed during plate-loading tests on the same experimental pavements. To this end, the research included RPB and FWD tests on the six paved soil test sections selected from the 24 test sections at Winchendon, Massachusetts.

But the validation of moduli determined by laboratory tests was only one of the two principal objectives of the field testing. Laboratory testing alone does not provide the time-dependent evaluation of the resilient modulus of the various layers of the pavement structure that is needed for pavement evaluation and design. The stresses needed for evaluating the resilient modulus can be calculated in relation to the particular traffic loading for which the pavement analysis is being made, but in-situ seasonal variation of temperature and moisture tension must also be assessed to permit determinaton of resilient moduli through a complete annual cycle. Subsurface temperatures, frost depths, and moisture tension are among the parameters that can be predicted by means of the mathematical model of frost heave being developed under another phase of this research project (Guymon et al., in prep.). Alternatively, temperatures and moisture tensions can be monitored in-situ throughout the year to provide the needed link for laboratory assessment of time-dependent seasonal variation of resilient modulus. This was the second objective of the field work at Winchendon.

Subsurface temperatures were monitored throughout the year at each of the six test sections at Winchendon, by means of thermocouples installed at various depths. Soil moisture tensiometers (McKim et al. 1976) also were installed at various depths in each test section and were read each time a plate-bearing test was performed.

Field in-situ plate-bearing tests using pulsed loading were performed to verify the laboratory-determined moduli and as a means of evaluating seasonal variations in the moduli. Two types of in-situ tests were performed on the six Winchendon

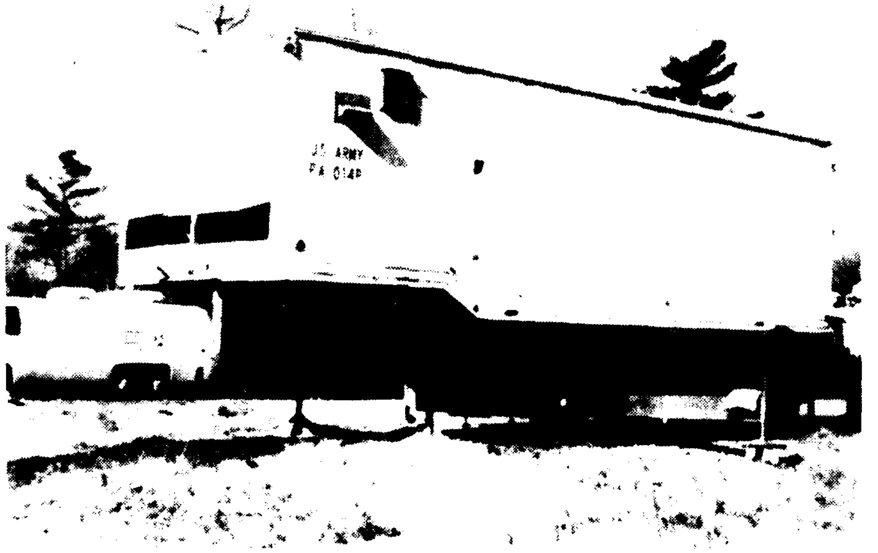


Figure 7. RPB test van with reference beam for LVDTs.

test sections. The first type was the repeated-load plate-bearing test (RPB). The equipment is mounted in the center of a large enclosed semi-trailer (Fig. 7), which is ballasted and reinforced to provide a firm reaction for the plate load. The load was applied by an air actuator, and loads up to about 53 kN can be applied at frequencies up to about 20/min. A load ell located on top of the plate senses each load repetition, which is recorded on strip charts. The recorder also traces the outputs of linear variable differential transformers (LVDTs) supported by a reference beam and placed in contact with the pavement surface at various radial distances from the loading plate to measure resilient deflections. The loads were applied through a 304-mm-diameter plate, and were repeated 50 to 1000 times. The pulse duration was about 1 sec and the cycle time was about 3 sec.

The second type of in-situ test equipment used was a falling weight deflectometer (FWD) (Koole 1979). In the device we used (Fig. 8), a mass of 150 kg falls freely and strikes a shock-absorbing device

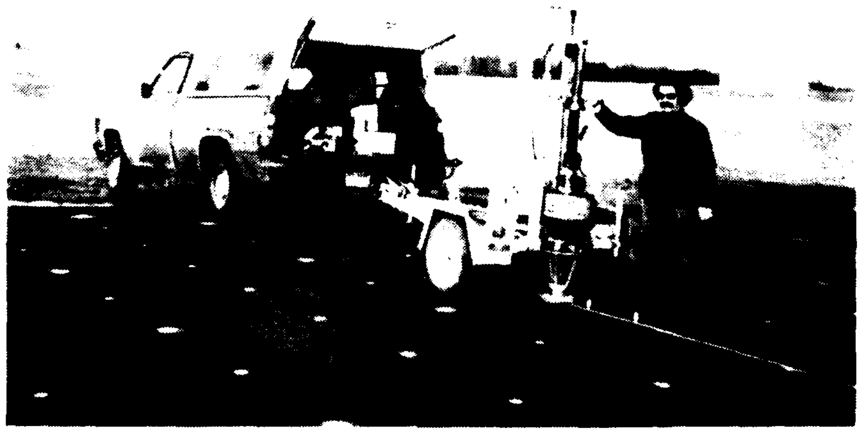


Figure 8. FWD in use at Albany County Airport, Albany, N.Y.

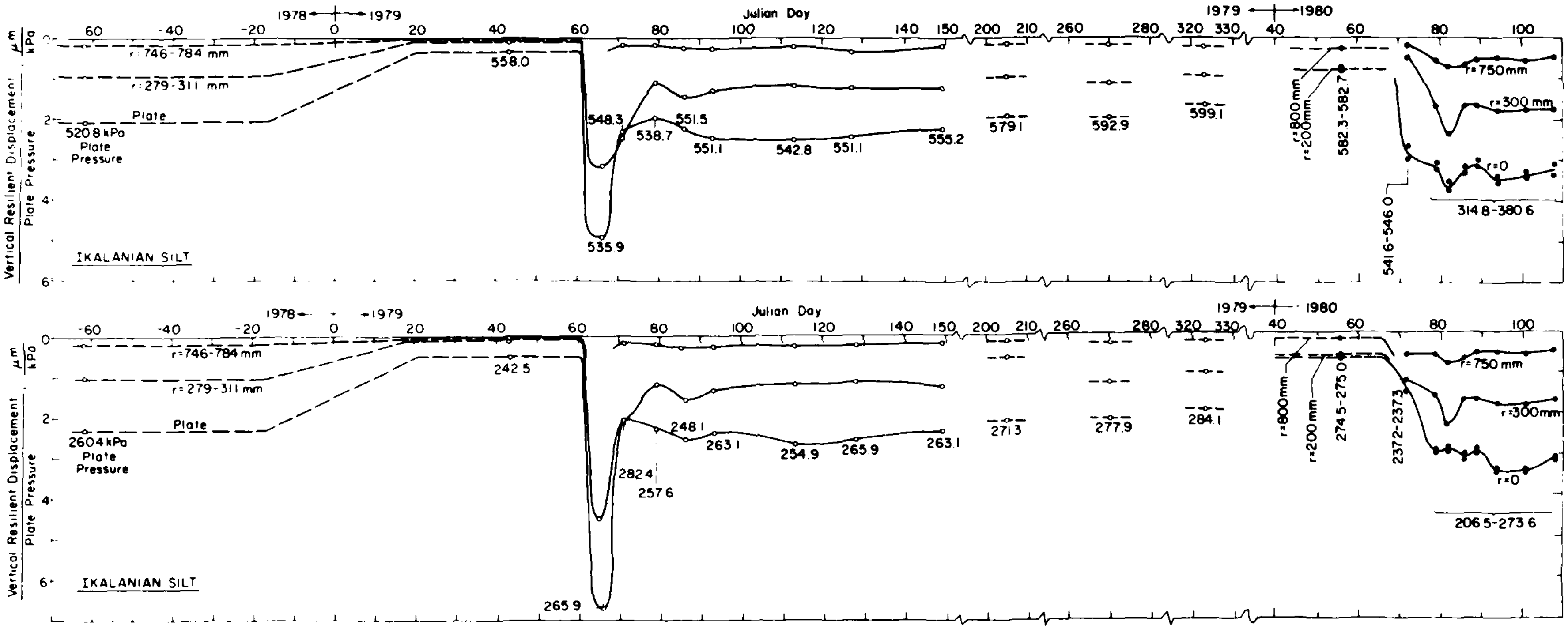


Figure 9. Vertical resilient displacement at two load levels and three radii, Ikalanian sand test section.

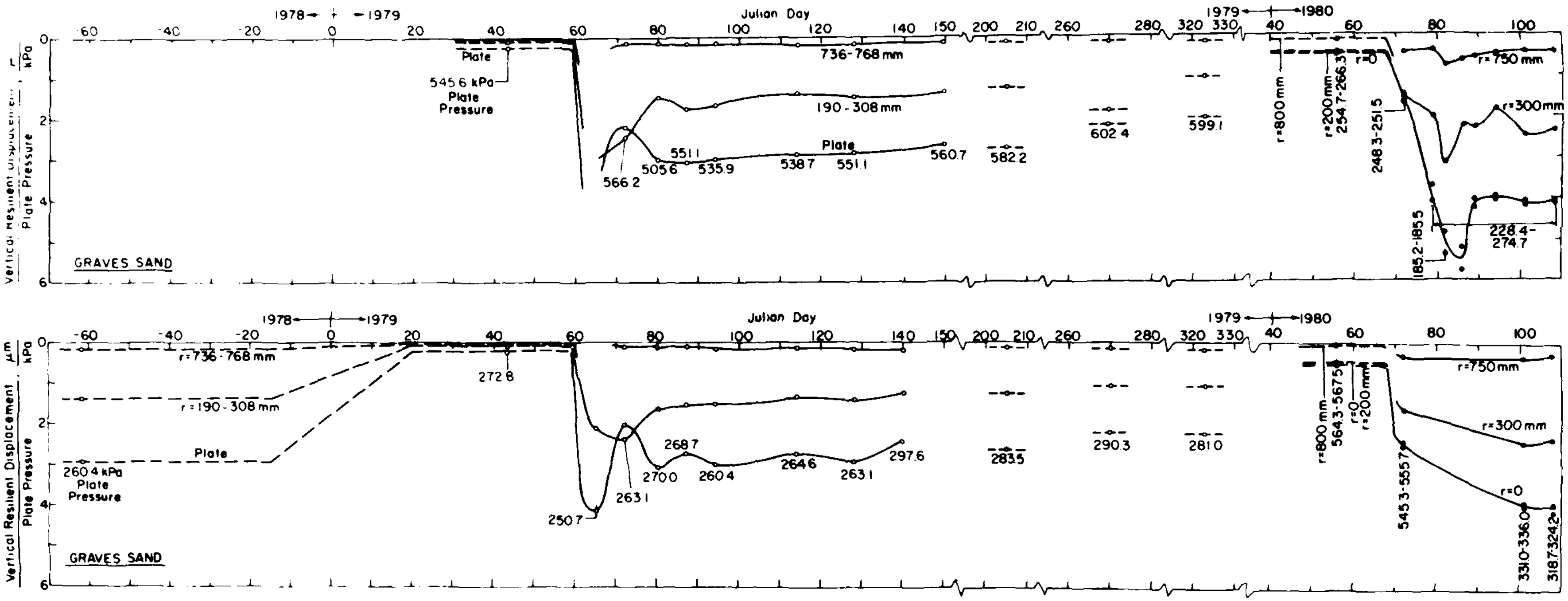


Figure 10. Vertical resilient displacement at two load levels and three radii, Graves sand test section.

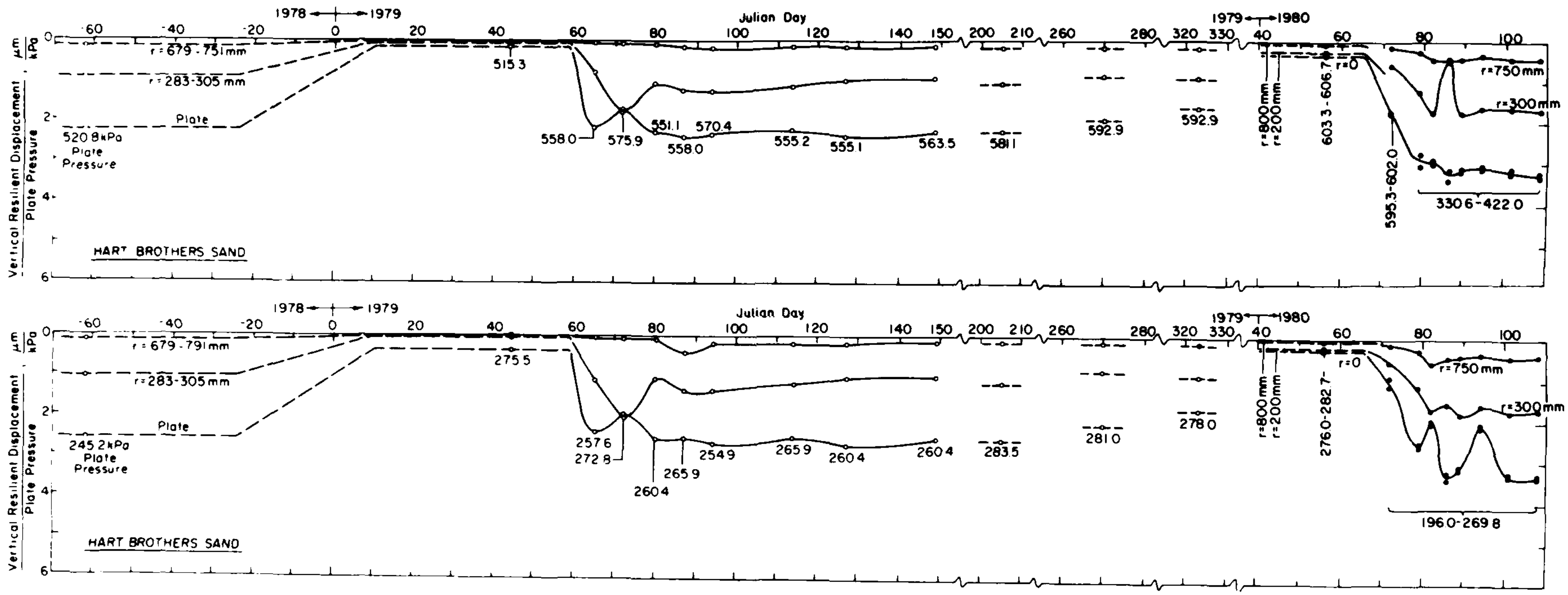


Figure 11. Vertical resilient displacement at two load levels and three radii, Hart Brothers sand test section.

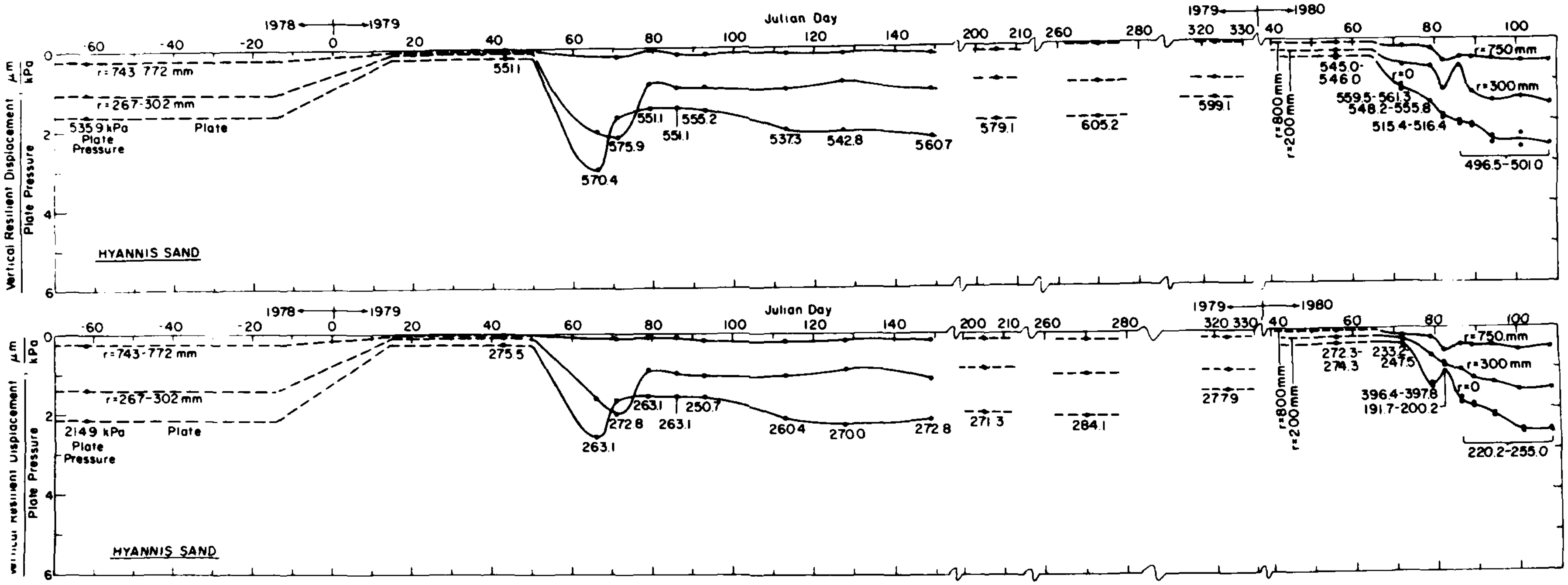


Figure 12. Vertical resilient displacement at two load levels and three radii, Hyannis sand test section.

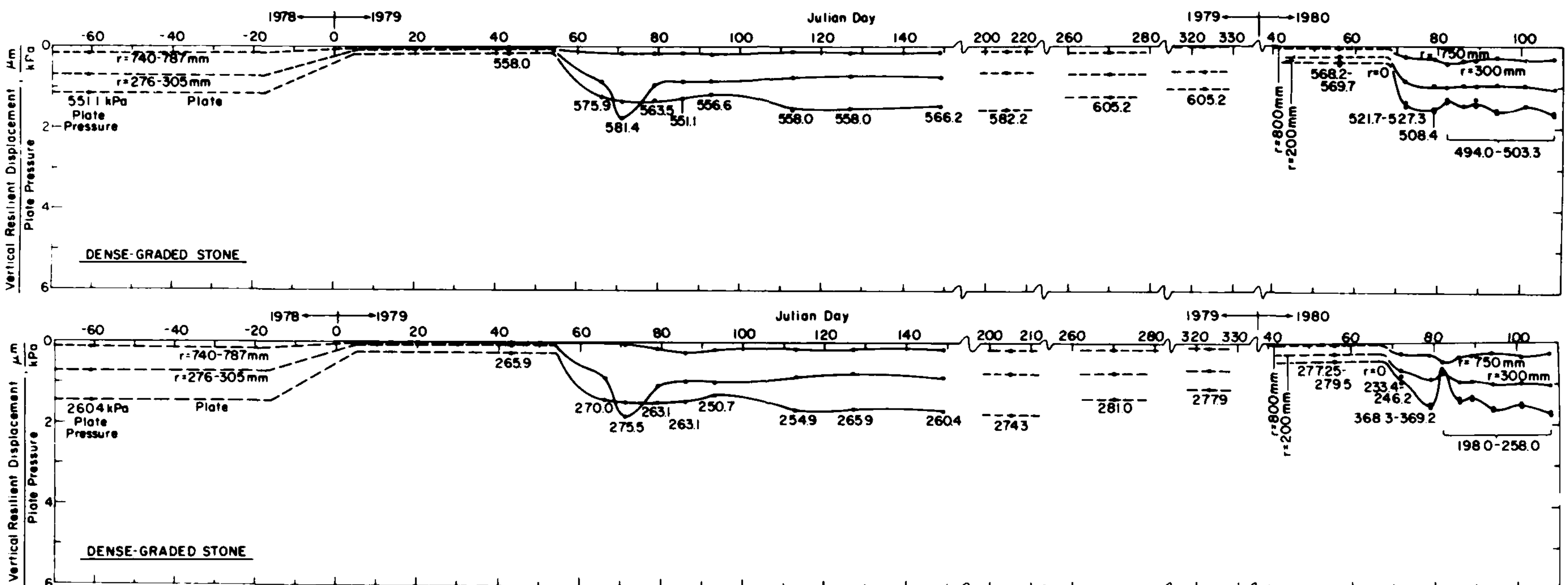


Figure 13. Vertical resilient displacement at two load levels and three radii, dense-graded stone test section.

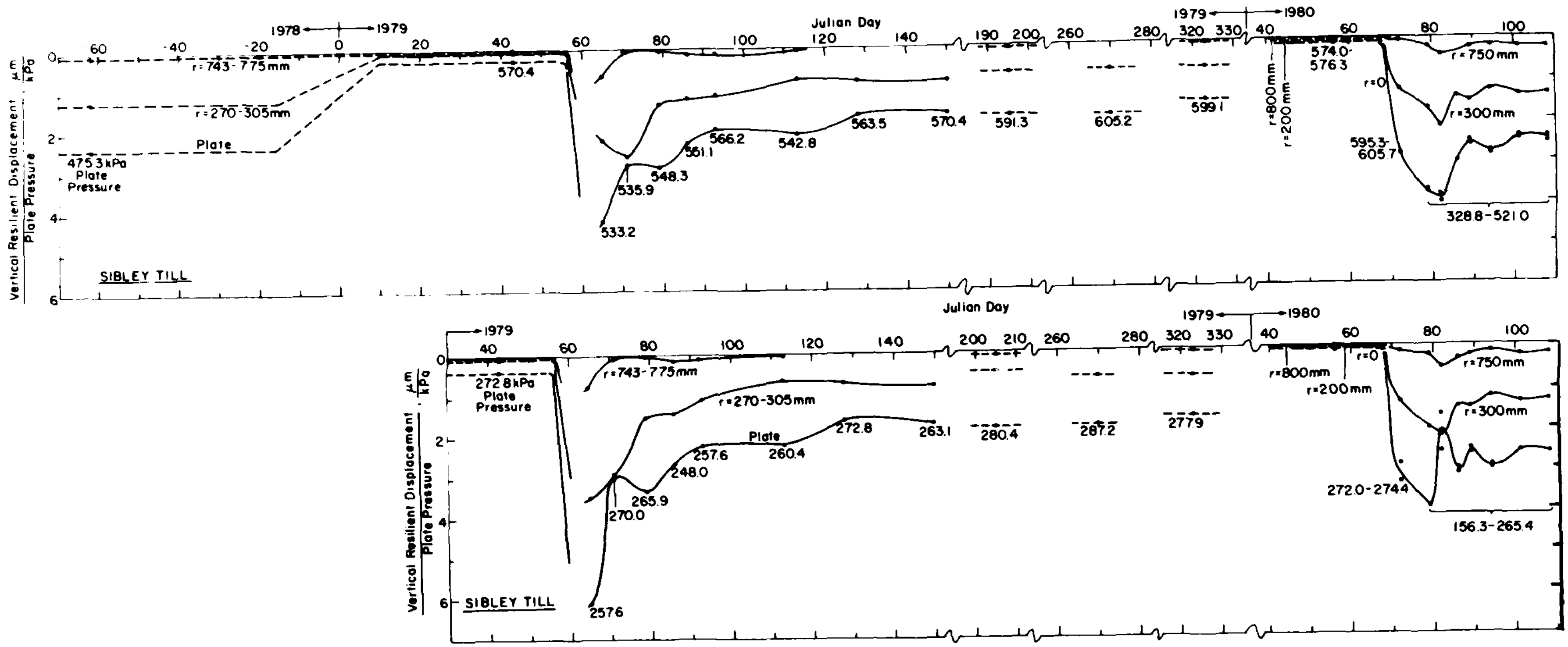


Figure 14. Vertical resilient displacement at two load levels and three radii, Sibley till test section.

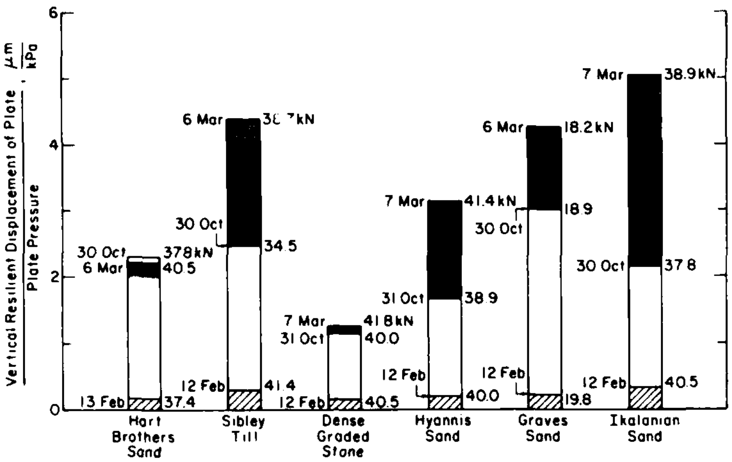


Figure 15. Vertical resilient displacement observed on six test sections prior to freezing, while frozen, and during thawing.

that imparts a 28-ms pulse load to a 300-mm-diameter plate resting on the pavement surface. Three velocity transducers (geophones) are positioned in contact with the pavement, at the center of the plate (through a small aperture in the plate) and at two radial distances from the center. Associated instrumentation integrates the velocity signal and reads out vertical displacement of the pavement in micrometers. The load imparted to the pavement is monitored by a load cell, and the output is calibrated to give plate pressure in kilopascals. For the investigation of the resilient modulus of nonlinear soils, we employed two drop heights giving pressures from 200 to 800 kPa and total loads from about 15 to 50 kN. We made five drops at each height, and repeated each test sequence a second time after repositioning the geophones to obtain deflection measurements at a total of five radii.

The RPB tests were performed on the six test sections at two load levels on 13 occasions between October 1978 and September 1979, encompassing dates on which the test soils were frozen, partially thawed, fully thawed, recovering, and fully recovered. The FWD tests were performed on the same six test sections at two load levels on nine occasions between February and April 1980 with soils in the frozen, thawed, and recovering conditions. On each occasion pavement and test soil temperatures as well as moisture tension levels were determined. All the field test data are summarized in Appendix A. The ground temperatures prevailing during each RPB and FWD test are shown graphically in Appendix B.

The vertical resilient displacements under plate loads observed first in the fall of 1978 decreased to small measurements in the second series of tests in February 1979, when the test soils were frozen. As the plate pressure differed somewhat in the various tests, the displacements shown in Figures 9 to 14 are normalized by dividing by the plate pressure. The plots show the sharp increase in displacement that is observed in the first test after thawing starts. The increase in surface deflection upon thawing is particularly great for the four test soils that contain the greatest fractions of fines (material passing the No. 200 sieve): the Ikalanian, Graves, and Hyannis sands and the Sibley till. Even in these soils a substantial decrease in deflection (recovery) was observed within 10 to 20 days after thawing started. In the Hart Brothers sand and the dense-graded stone the increased deflection upon thawing did not differ greatly from the fall (recovered) deflection. The comparative response of the six soils to thawing is illustrated in Figure 15.

ANALYSIS OF FIELD-LOADING TESTS

The principal objective in selecting or developing a method for analysis of the deflection basins

was to be able to calculate the deflection basin resulting from application of a known load to a pavement system of a known thickness of the layers, each having linear or nonlinear resilient modulus and Poisson's ratio determined in advance by laboratory testing (forward approach). Comparison of the calculated deflection basin with the basin actually observed in field tests would permit validation of the laboratory testing procedures. Achieving a degree of success in meeting this objective led to identification of a secondary objective: to calculate the linear or nonlinear moduli corresponding to a known deflection basin (backward approach).

To meet the dual objectives, the two alternatives of the finite-element analysis and the elastic layered system analysis were considered. The finite-element analysis has the important advantage that the modulus within each layer can vary in the radial direction for compatibility with the variation in stress. Because the entire stress regime beneath the pavement must be defined, however, computational costs would be high for a system with a sufficiently large number of elements, and doubtless prohibitively high for use with the backward approach. Consequently we selected the elastic layered system analysis. The CHEVRON computer code, including the recently developed COFE subroutine, was modified by L.H. Irwin (Irwin and Johnson 1981) to incorporate a "front end" that, for each nonlinear layer, begins with an assumed modulus, calculates the stress in the layer, uses the laboratory-developed model of stress dependency to calculate a modulus, and thereafter iterates until compatible moduli and stresses are calculated. The program, termed NELAPAV (nonlinear elastic layer analysis for pavements) then calculates stresses, strains, and deflections in the same manner as CHEVRON. An innovative feature of NELAPAV is its ability to reduce the problem of inability to account for the change in elastic modulus within a layer as the distance from the axis of the load increases. This is accomplished by recomputing the set of stress-compatible moduli for each combination of radius and depth that defines a point of interest at which stresses, strains, and deflections are to be computed. While the modulus cannot vary radially for the calculations of responses at any individual point, different stress-compatible moduli are used for calculations at other radii. The hypothesis presumes that the moduli of the materials closest to the point of interest have the greatest influence on the state of stress at that point. In this way NELAPAV accounts to some extent for the horizontal variations in moduli.

NELAPAV has been structured to incorporate five basic models of stress dependency. The program user may select one of these models for each pavement layer. The models include:

Type 1: $M_r = \text{constant}$

Type 2: $M_r = K_1 J_1^{K_2}$

Type 3: $M_r = K_2 + (K_1 - \sigma_d)K_3, \; \sigma_d < K_1$

$M_r = K_2 + (\sigma_d - K_1)K_4, \; \sigma_d > K_1$

Type 4: $M_r = K_1 (J_2/\tau_{oct})^{K_2}$

Type 5: $M_r = K_1 (\tau_{oct})^{K_2}$

where M_r, J_1, σ_d, J_2, and τ_{oct} are as defined earlier, and K_1, K_2, K_3, and K_4 are regression constants.

In forward analyses of the six test sections, we have used the type 1 model for the asphalt concrete, types 1, 4, and 5 for the frozen test soils, and types 2 and 4 for the thawed and recovered test soils and the natural subgrade test soil. As the analyses proceeded, the type 4 model came to be preferred over the type 2 model for thawed soils. It was considered that the type 4 model has potential for extensive application to nonlinear soils because it incorporates a shear stress parameter and also (possibly for that reason) the laboratory characterization equations of that form yielded higher values of R^2. In recent years many investigators have concluded that the conventional model of resilient modulus as a function of J_1, represented by type 2, has serious limitations and that nonlinear models for granular materials need to account for the effect of shear strain (e.g. Brown and Pappin 1981, May and Witczak 1981). The type 4 model has the potential of accounting (indirectly) for shear stresses and strains through the inclusion of τ_{oct}, while still keeping the model very simple and avoiding computational complexities.

In addition to selecting a model for resilient modulus and inputting the applicable values for the regression constants, appropriate values for the resilient Poisson's ratio are needed. In most cases the results of the analysis are not highly sensitive to moderate changes in Poisson's ratio, which may be evaluated by tests on each material or by assigning values consistent with published test data on similar materials. Tests on the various

materials from the Winchendon test sections included measurement of axial and radial resilient strains. Poor correlation with other parameters that were monitored makes interpretation of the data uncertain (Cole et al. 1986). Accordingly, values of Poisson's ratio were selected from experience with other materials and from published test data (Table 3).

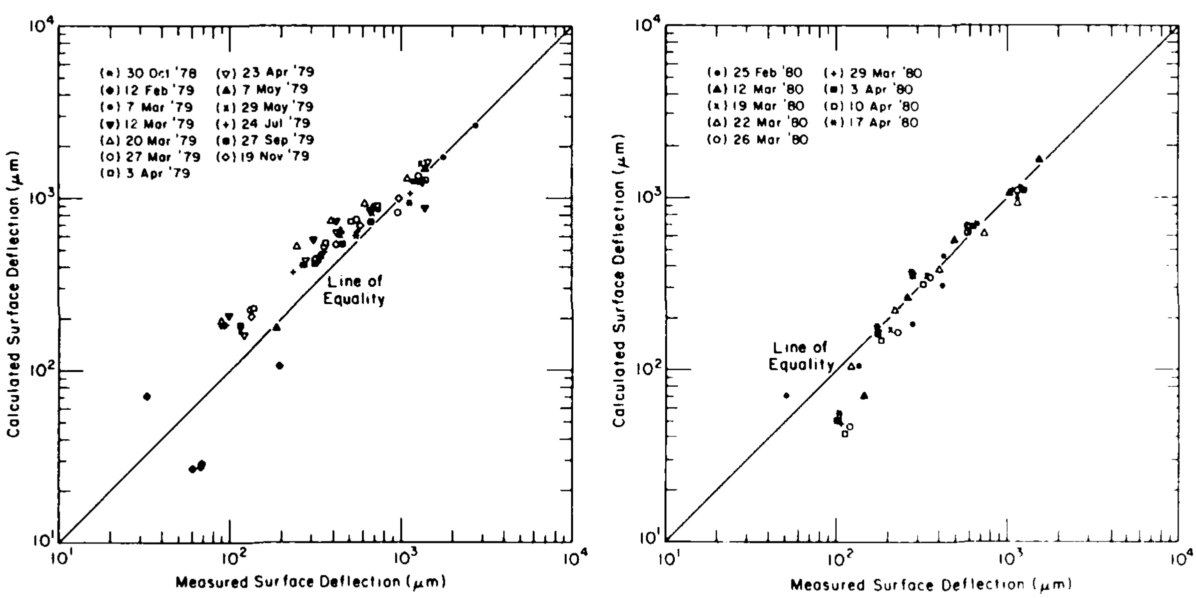
Each of the 22 RPB and FWD tests conducted at each of the six test sections has been analyzed by the forward approach. The temperatures and/or moisture tensions prevailing in the test sections at the time of each test, together with the plate-bearing pressures measured for each test and moisture contents and dry densities when applicable, were taken as given values, and the stress dependency model appropriate to each layer was selected. Initial assumed values of moduli for the nonlinear layers were selected. NELAPAV calculated stresses, strains, displacements, and stress-compatible moduli throughout the system.

Table 3. Values of Poisson's ratio used in analysis.

Asphalt concrete	$T < -2°C$	0.30
	$-2 < T < +1$	0.35
	$+1 < T < +8$	0.40
	$+8 < T < +16$	0.45
	$T > +16$	0.50
Test soils		
Frozen		
Thawed	$\psi < 2$ (to 4) kPa	0.30–0.35
	2 (to 4) $< \psi <$ 8 (to 10)	0.45
	$\psi <$ 8 (to 10)	0.40
		0.35
Subgrade		0.35

The comparisons between the calculated and measured deflections for the higher of the two plate loads are summarized in Figures 16–21; the comparison is similar for the lower loads (Appendix C). Deflection measurements were made at five different radii. Each of these measurements is plotted and compared with the corresponding deflection computed by NELAPAV on the basis of the conditions of the pavement system prevailing on each particular date.

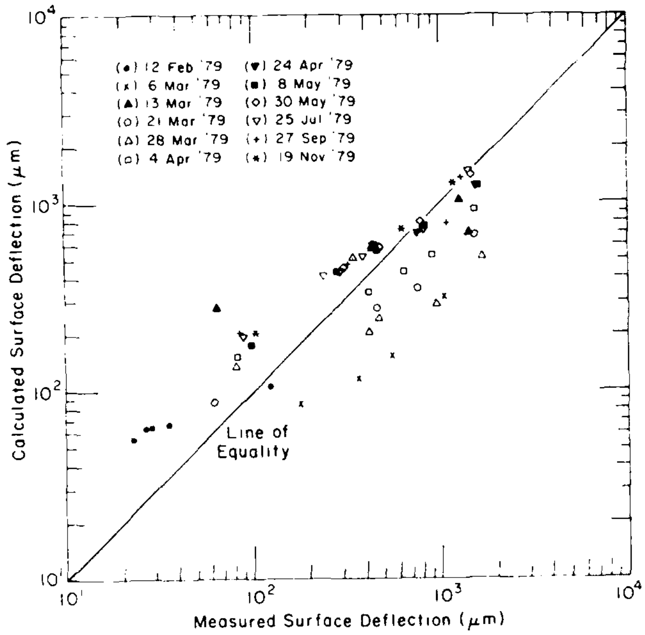
Several general trends are apparent in these plots. The maximum deflections, at the center of the basin, calculated by NELAPAV tend to agree well with the maximum surface deflections measured in both the RPB and FWD tests. Proceeding outward from the plate, the different test sections



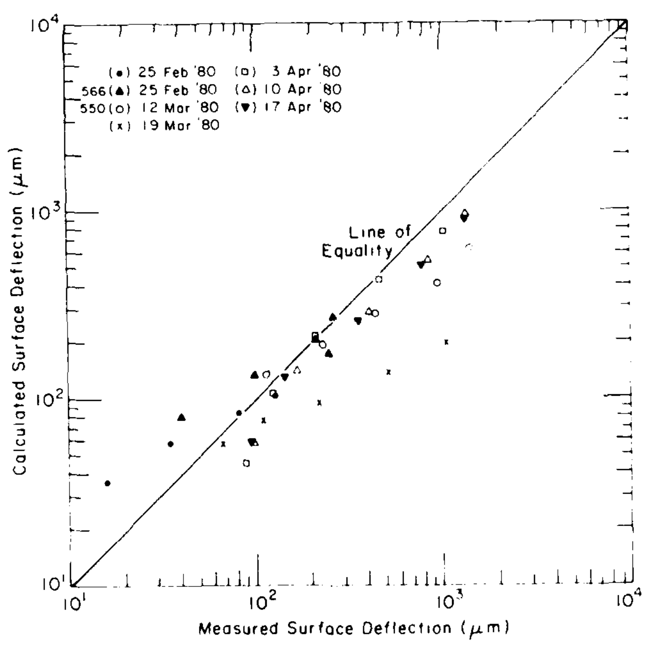
a. 1979 RPB tests.

b. 1980 FWD tests.

Figure 16. Measured surface deflections compared with deflections calculated by NELAPAV, Ikalanian sand test section.

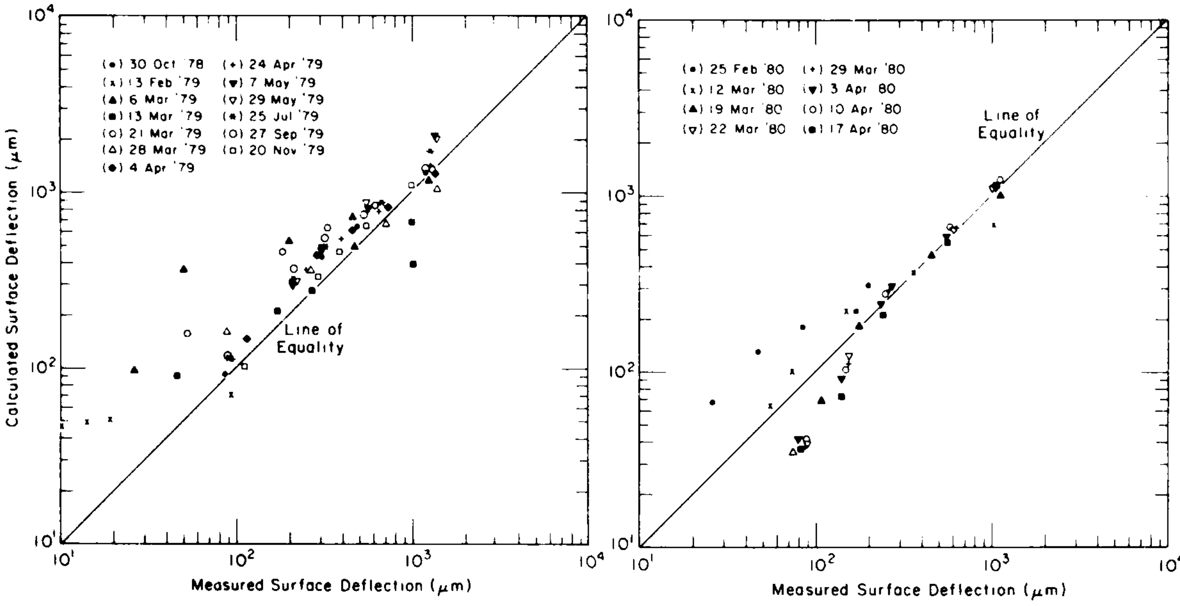


a. 1979 RPB tests.



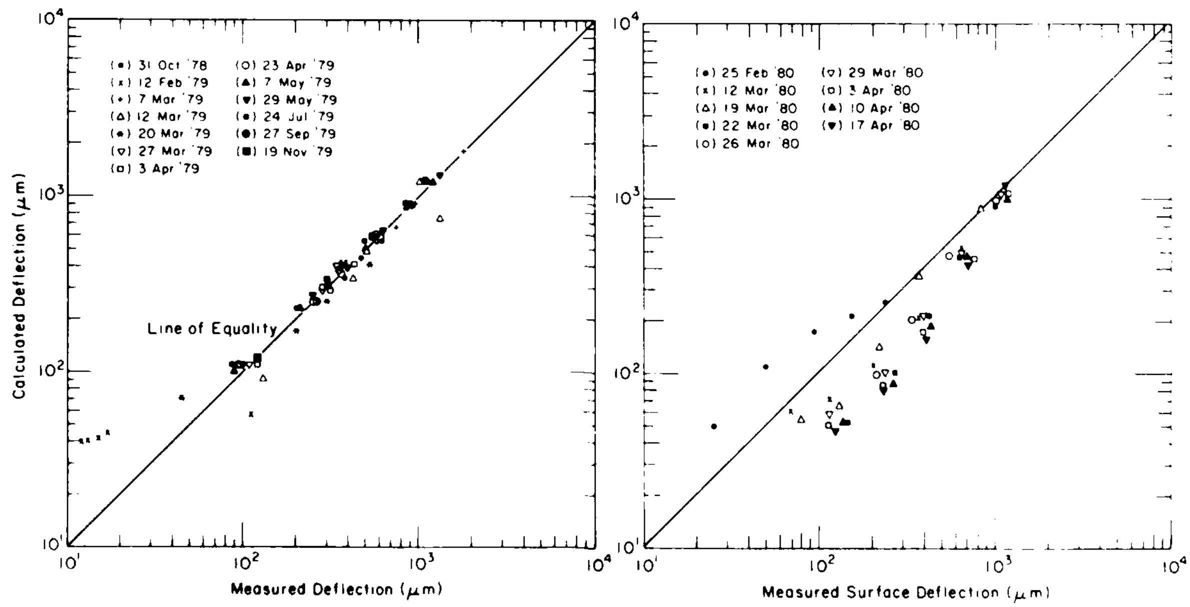
b. 1980 FWD tests.

Figure 17. Measured surface deflections compared with deflections calculated by NELAPAV, Graves sand test section.



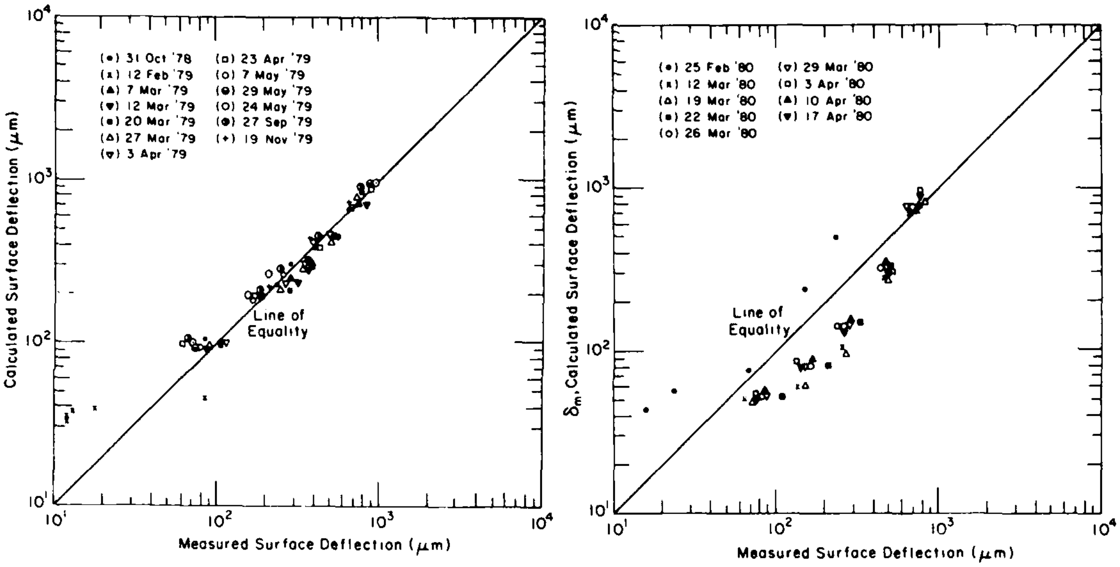
a. 1979 RPB tests. *b. 1980 FWD tests.*

Figure 18. Measured surface deflections compared with deflections calculated by NELAPAV, Hart Brothers sand test section.



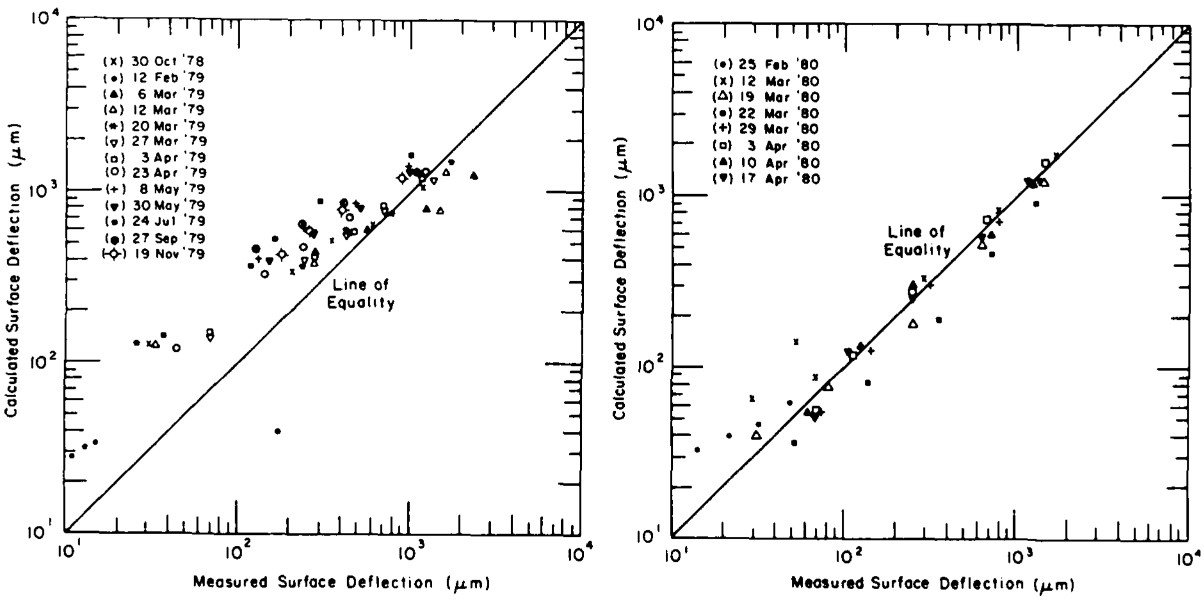
a. 1979 RPB tests. *b. 1980 FWD tests.*

Figure 19. Measured surface deflections compared with deflections calculated by NELAPAV, Hyannis sand test section.



a.1979 RPB tests *b. 1980 FWD tests.*

Figure 20. Measured surface deflections compared with deflections calculated by NELAPAV, dense-graded stone test section.



a. 1979 RPB tests. *b. 1980 FWD tests.*

Figure 21. Measured surface deflections compared with deflections calculated by NELAPAV, Sibley till test section.

show varying degrees of agreement between the calculated and measured basins as the outer radii are considered. The Hyannis sand and dense-graded stone test sections both show very good agreement all the way to the tails of the basins in the RPB tests, differing only for tests in the frozen condition. In the other test sections the RPB basins generally have calculated displacements that are higher than the measured displacements. This could be because the supports for the reference beam for measuring of deflections in the RPB test may in some cases be within the deflection basin. Thus, a possible explanation for these results is that the real deflections in the RPB tests may have been greater than those recorded. Excellent agreement is found between the calculated deflections and the deflections measured in FWD tests on Ikalanian sand, Hart Brothers sand, and Sibley till, while somewhat more scatter is evident in the plots for the other test sections.

Perhaps the most significant observation is the reasonably good agreement of the postthaw basins in general. The calculated and measured deflections differ more on those dates when the cross section included layers of frozen soil. This problem can be attributed in part to uncertainties in the definition of the exact thickness of the frozen layers. Such uncertainty, in turn, may derive in part from interpolation of ground temperatures within the vertical string of sensors and in part from the assumption that the transition from frozen to thawed conditions occurs precisely at 0°C. For those dates with a frozen layer, the calculated deflections are generally greater than the measured deflections. An example of a thawed basin exhibiting good agreement is shown in Figure 22. Figure 23 shows the poor agreement of a basin that contained a frozen layer.

The calculated resilient moduli and other results from the analysis of the six test sections are sum-

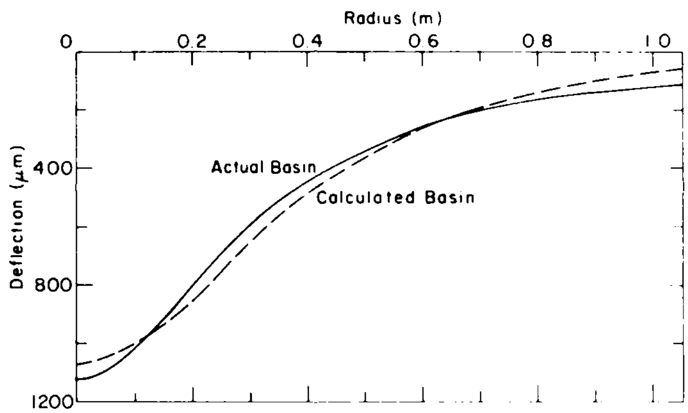


Figure 22. Calculated and actual deflection basins for 10 April 1980, Ikalanian sand: Drop height 100 mm and plate pressure 331.6 kPa.

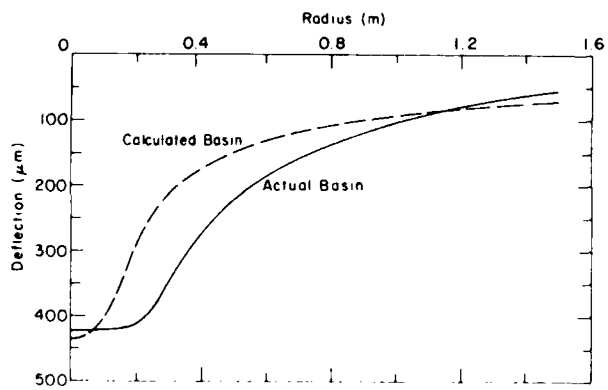


Figure 23. Calculated and actual deflection basins for 25 February 1980, Ikalanian sand: Drop height 219 mm and plate pressure 582.2 kPa.

marized in Appendix D. The resilient moduli of the test soils calculated by NELAPAV show the expected seasonal variation, with extremely high values in the frozen condition, decreasing dramatically upon thawing, and increasing somewhat during the late spring, summer, and fall. A sampling of the seasonal variation in modulus is given in Table 4, representing the upper 250–325 mm of the Ikalanian sand. The increase of the modulus from spring to fall is not as great as has been observed in earlier research on a finer grained soil (Johnson et al. 1978). The relatively modest increase during the recovery phase is believed to be attributable to the high water table at the Winchendon site, which severely restricts the build-up of moisture tension in the test soils. Another sampling of the variation in modulus is given in Table 5, representing the upper 250 mm of the dense-graded stone. In the case of this coarse-grained crushed stone, while the modulus is extremely high in the frozen condition, it decreases upon thawing to approximately the same level that prevails in the fall. That is to say, this material is found to be not susceptible to thaw weakening. Similar tabulations for the other test soils are given in Tables 6–9. It is apparent that the test dates early in the thawing period did not coincide exactly with the brief period when the modulus of the upper layer is at its minimum level. An interpretation of the variation in modulus of the upper layer of each

Table 4. Calculated resilient modulus (MPa) in upper layer of Ikalanian sand beneath center of plate.

	Top 250 mm, 1979			*Top 325 mm, 1980*	
	250–280 kPa Plate pressure	*530–590 kPa Plate pressure*		*210–275 kPa Plate pressure*	*320–585 kPa Plate pressure*
30 October 1978	77.7	105.3	25 February 1980		
12 February 1979	8257.9	5996.0	thawed, top 100 mm	32.7	49.9
7 March 1979	12.2	17.3	frozen, next 225 mm	1956.7	1432.9
12 March 1979	33.8	46.4	12 March 1980	42.0	43.3
20 March 1979	42.2	59.1	19 March 1980	30.9	35.5
27 March 1979	38.5	55.7	22 March 1980	35.1	40.9
3 April 1979	41.4	57.4	26 March 1980	32.7	38.3
23 April 1979	49.3	69.9	29 March 1980	31.2	35.4
7 May 1979	54.0	75.3	3 April 1980	26.3	31.5
29 May 1979	55.8	78.8	10 April 1980	31.3	36.5
24 July 1979	91.6	126.1	17 April 1980	31.9	36.6
27 September 1979	84.0	118.0			
19 November 1979	77.3	107.2			

Table 5. Calculated resilient modulus (MPa) in upper layer of dense-graded stone beneath center of plate.

	Top 250 mm, 1979			*Top 250 mm, 1980*	
	249–276 kPa Plate pressure	*547–597 kPa Plate pressure*		*201–278 kPa Plate pressure*	*451–569 kPa Plate pressure*
31 October 1978	100.8	107.3	25 February 1980	101.6	110.9
12 February 1979	32,664.0	32,664.0	12 March 1980	89.5	97.4
7 March 1979	89.0	95.8	19 March 1980	93.4	96.7
12 March 1979	89.1	95.9	22 March 1980	87.6	95.4
20 March 1979	87.9	94.7	26 March 1980	90.6	96.1
27 March 1979	91.5	94.4	29 March 1980	91.4	96.3
3 April 1979	98.0	104.5	3 April 1980	90.0	94.9
23 April 1979	90.8	96.9	10 April 1980	98.5	104.3
7 May 1979	95.5	101.5	17 April 1980	91.0	95.8
29 May 1979	90.6	96.7			
24 July 1979	97.5	104.2			
27 September 1979	97.6	103.9			
19 November 1979	99.9	106.6			

Table 6. Calculated resilient modulus (MPa) in upper layer of Graves sand beneath center of plate.

	Top 350 mm, 1980	
	159–267 kPa Plate pressure	*240–566 kPa Plate pressure*
25 February 1980	1489.0	917.4
12 March 1980		
thawed, top 100 m	66.5	96.7
frozen, next 250 mm	1723.3	962.4
19 March 1980		
thawed, top 124 mm	90.6	—
frozen, next 326 mm	1389.4	—
22 March 1980	31.0	—
26 March 1980	42.9	—
29 March 1980	37.1	44.0
3 April 1980	43.0	47.2
10 April 1980	41.7	47.8
17 April 1980	47.8	54.4

test soil, under the lower of the two test loads, is given in Figure 24.

Only very limited application of the backward approach has been made (Irwin and Johnson 1981). Its special utility is the calculation of resilient moduli for a pavement's supporting layers on which no laboratory characterization tests have been performed. Since laboratory characterizations are available for all the test soils, the backward approach has only been tested to evaluate its effectiveness. In the calculations, the resilient modulus of the natural subgrade was assumed to be known and was assigned a value previously calculated by NELAPAV from a forward analysis based upon the laboratory nonlinear material characterization. This value was assigned merely for convenience, and in reality it is unnecessary to use NELAPAV, which calculates the stresses generated by both overburden materials and the plate load. At such relatively great depth the effect of the plate load is slight, and an approximation of the modulus based upon a simple estimate of overburden pressure would suffice.

After assigning a modulus value for the natural subgrade, the procedure is to start at the outermost radial point at which deflections were measured, assign reasonable moduli to the upper layers, and determine the modulus of the lower layer of the test soil by trials with NELAPAV to give deflections at that radius matching the measured deflections. This latter modulus, and the subgrade modulus, are carried inward to the center of the plate ($r = 0$), together with reasonable moduli for the upper layers of test soil, so that the asphalt concrete modulus can be determined by trials with NELAPAV to give deflections at $r = 0$ matching the measured deflections. The assumed values of the moduli of the upper layers of test soil are then adjusted by successive trials with NELAPAV to give a better fit with the measured deflections at the intermediate radii. After several iterations

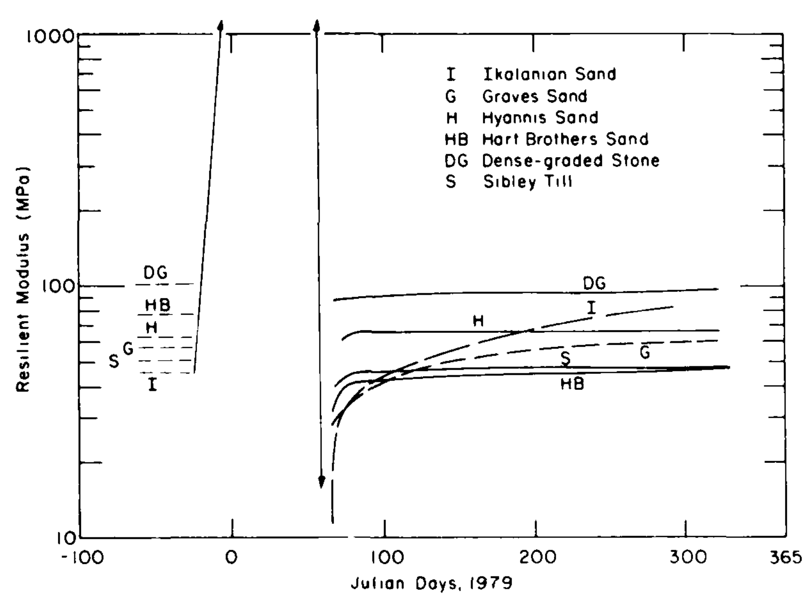


Figure 24. Interpretation of seasonal variation in resilient modulus of six test soils directly beneath asphalt pavement under 200–300 kPa plate pressure.

Table 7. Calculated resilient modulus (MPa) in upper layer of Hart Brothers sand beneath center of plate.

	Top 250 mm, 1979			*Top 250 mm, 1980*	
	244–283 kPa Plate pressure	*530–590 kPa Plate pressure*		*197–279 kPa Plate pressure*	*331–605 kPa Plate pressure*
30 October 1978	44.8	48.9	25 February 1980	670.4	793.3
13 February 1979	4872.5	4872.5	12 March 1980	122.5	180.8
6 March 1979	31.1	37.7	19 March 1980	23.1	26.1
13 March 1979	40.3	52.8	22 March 1980	18.4	20.9
21 March 1979	41.6	45.1	26 March 1980	19.8	22.9
28 March 1979	41.5	47.0	29 March 1980	20.0	21.6
4 April 1979	40.5	44.8	3 April 1980	27.6	29.4
24 April 1979	45.1	48.2	10 April 1980	25.8	27.4
7 May 1979	38.6	40.3	17 April 1980	26.9	28.6
29 May 1979	35.6	37.9			
25 July 1979	48.0	49.0			
27 September 1979	45.3	48.9			
20 November 1979	48.5	54.4			

Table 8. Calculated resilient modulus (MPa) in upper layer of Hyannis sand beneath center of plate.

	Top 250 mm, 1979			*Top 250 mm, 1980*	
	214–281 kPa Plate pressure	*512–597 kPa Plate pressure*		*196–379 kPa Plate pressure*	*439–560 kPa Plate pressure*
31 October 1978	62.2	69.0	25 February 1980	1996.8	1996.8
12 February 1979	29,993.9	29.993.9	12 March 1980	85.6	104.8
7 March 1979	21.0	21.0	19 March 1980	76.8	82.8
12 March 1979	21.0	21.0	22 March 1980	65.9	76.6
20 March 1979	67.6	78.0	26 March 1980	65.8	72.4
27 March 1979	65.5	73.1	29 March 1980	63.5	70.8
3 April 1979	65.1	73.2	3 April 1980	62.1	67.9
23 April 1979	64.5	70.6	10 April 1980	65.0	72.5
7 May 1979	63.3	70.1	17 April 1980	62.0	68.0
29 May 1979	62.3	68.9			
24 July 1979	67.7	76.7			
27 September 1979	68.4	77.1			
19 November 1979	68.8	75.1			

Table 9. Calculated resilient modulus (MPa) in upper layer of Sibley till beneath center of plate.

	Top 250 mm, 1979			*Top 250 mm, 1980*	
	246–283 kPa Plate pressure	*472–597 kPa Plate pressure*		*167–300 kPa Plate pressure*	*330–600 kPa Plate pressure*
30 October 1978	—	51.5	25 February 1980	3449.0	3449.0
12 February 1979	8046.0	8046.0	12 March 1980	40.2	44.6
7 March 1979	39.8	39.8	19 March 1980	39.4	41.1
12 March 1979	40.1	43.9	22 March 1980	37.9	40.9
20 March 1979	42.4	46.1	26 March 1980	39.5	—
27 March 1979	43.9	48.2	29 March 1980	39.7	43.2
3 April 1979	46.4	50.9	3 April 1980	40.7	44.3
23 April 1979	46.5	50.7	10 April 1980	39.6	43.2
8 May 1979	47.7	50.7	17 April 1980	42.3	45.3
30 May 1979	44.6	48.9			
24 July 1979	49.1	51.6			
27 September 1979	43.4	47.0			
19 November 1979	46.7	50.5			

with slightly adjusted values of the moduli, reasonable stability of the resulting deflection basin can usually be obtained.

In the above procedure, the Type 1 model of NELAPAV, for linear moduli, is used. A computer program for linear elastic materials, MODCOMP I, has been developed for application of NELAPAV in the backward approach (Irwin 1981). It has not been applied to the nonlinear materials of the Winchendon test sections, except to check and validate the concepts and operation of the program.

DISCUSSION

The reasonably good agreement of the postthaw basins is taken as evidence that the expressions for nonlinear resilient moduli derived from laboratory tests are acceptable. Thus the adopted laboratory procedures for determining seasonal variations in resilient modulus are seen as adequately validated for soils of the types tested, and the results of tests according to that procedure should provide a useful basis for evaluating and designing new and rehabilitated pavements in cold regions.

The application of materials characterizations in the form of expressions for nonlinear resilient modulus derived from laboratory tests requires use of a pavement response model that can account for the stress dependency of the modulus. NELAPAV has given good results in the analysis of the Winchendon field data and is seen as a useful analytical tool.

An important characteristic of the laboratory-test-derived expressions for resilient modulus is the further dependence of the modulus upon site-specific environmental parameters that vary widely throughout the annual cycle of seasonal changes. The principal parameters are temperature and moisture tension. Consequently, assessment of the seasonal variation in the modulus prevailing in a material for which a laboratory nonlinear characterization has been developed requires not only a calculation of the stress in the material but field observation of temperature and moisture tension as well. Such field observations of conditions prevailing in the various layers in existing pavements can be obtained by installing sensors and collecting data over a complete annual cycle. Data obtained from undeveloped terrain where a new pavement is planned may be inapplicable to the future conditions after construction. An alternative to field data collection is to predict temperatures and moisture tensions by means of a mathematical model of the freezing and thawing process. The frost heave model of Guymon et al. (in prep.) can be used for this purpose.

While the analysis of the field data as presented herein engenders reasonable confidence in the laboratory procedures for determining resilient modulus and assessing its seasonal variation, implementation in engineering practice should await further confirmation. Work recently completed on airfield pavements at Albany County Airport, N.Y., will enhance the data base and is expected to provide further confidence in the methodology. That work will be presented in separate reports (Cole et al., in prep., Johnson et al. 1986).

CONCLUSIONS

The research results summarized in this report lead to the following conclusions:

1. The analysis of field loading tests on six paved soil test sections at Winchendon, Mass., provided evidence that laboratory procedures (Cole et al. 1986), developed under this research project for deriving nonlinear materials characterizations of the six soils in the frozen and thawed conditions, are acceptable. While the laboratory procedures are considered to be validated for soils of the types tested, further confirming evidence is needed. Evidence on other nonlinear materials will be forthcoming from work recently completed at Albany County Airport, N.Y.

2. To make use of nonlinear materials characterizations, one needs an appropriate pavement response model that is capable of accounting for the stress dependency of the resilient modulus. NELAPAV, a computer program for nonlinear elastic layered analysis of pavements, is found to be a useful analytical tool.

3. The numerical value of the resilient modulus prevailing in a frozen or thawed pavement material at a given time cannot be calculated with the sole aid of an appropriate expression for the modulus derived from laboratory tests, but requires assessment of prevailing environmental conditions, principally temperature and moisture tension. These parameters can be monitored throughout an annual cycle by means of sensors installed in existing pavements, or their values throughout the year may be forecast by means of the frost-heave model of Guymon et al. (in prep.).

4. Limited application of the backward approach, an analytical procedure for determining resilient modulus from field measurements of surface deflection, indicates the validity of the approach. A computer program, MODCOMP I, was developed to calculate moduli in linear elastic materials.

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APPENDIX A: FIELD DATA

Winchendon, Mass., Test Sections

Table A1. Data from repeated-load plate-bearing (RPB) tests, Ikalanian sand test section.

Resilient Displacement at Two Load Levels

30 October 1978 (Day-63)

Load (kN):	18.9	37.8
Radius (mm)	Displacement (mm)	
140	0.6147	1.1202
311	0.2692	0.5232
387	0.1732	0.3505
450	0.1359	0.2667
762	0.0470	0.0909

12 February 1979 (Day 43)

Load (kN):	17.6	40.5
Radius (mm)	Displacement (mm)	
143	0.1251	0.1919
302	0.0167	0.0329
387	0.0211	0.0291
464	0.0190	0.0280
759	0.0105	0.0267

7 March 1979 (Day 66)

Load (kN):	19.3	38.9
Radius (mm)	Displacement (mm)	
140	1.8265	2.6994
286	1.2258	1.7419
375	0.8668	1.1719
467	0.5550	0.7280
--	--	--

12 March 1979 (Day 71)

Load (kN):	20.5	39.8
Radius (mm)	Displacement (mm)	
140	0.589	1.311
295	0.594	1.390
378	0.188	0.419
457	0.130	0.305
772	0.041	0.098

20 March 1979 (Day 79)

Load (kN):	18.7	39.1
Radius (mm)	Displacement (mm)	
133	0.602	1.098
279	0.312	0.607
394	0.196	0.387
479	0.115	0.247
784	0.050	0.088

27 March 1979 (Day 86)

Load (kN):	18.01	40.03
Radius (mm)	Displacement (mm)	
140	0.645	1.265
279	0.401	0.826
368	0.266	0.542
464	0.180	0.362
746	0.072	0.132

3 April 1979 (Day 93)

Load (kN):	19.1	40.0
Radius (mm)	Displacement (mm)	
140	0.6451	1.3842
292	0.3556	0.7303
371	0.2361	0.5017
460	0.1678	0.3536
746	0.0609	0.1376

23 April 1979 (Day 113)

Load (kN):	18.5	39.4
Radius (mm)	Displacement (mm)	
133	0.7048	1.4097
289	0.3149	0.6667
371	0.1999	0.4225
464	0.1345	0.2801
759	0.0643	0.1195

7 May 1979 (Day 127)

Load (kN):	19.3	40.0
Radius (mm)	Displacement (mm)	
149	0.6868	1.3879
289	0.3048	0.6909
371	0.1858	0.4490
457	0.1304	0.3342
752	0.0620	0.1849

29 May 1979 (Day 149)

Load (kN):	19.1	40.3
Radius (mm)	Displacement (mm)	
140	0.6413	1.2898
289	0.3404	0.6985
381	0.2026	0.4374
473	0.1359	0.2801
772	0.0530	0.1128

24 July 1979 (Day 205)

Load (kN):	19.8	40.3
Radius (mm)	Displacement (mm)	
137	0.5709	1.1160
283	0.2667	0.5588
378	0.1716	0.3574
470	0.1179	0.2371
762	0.0507	0.0936

27 September 1979 (Day 270)

Load (kN):	20.0	42.7
Radius (mm)	Displacement (mm)	
146	0.5779	1.1731
286	0.3302	0.6680
384	0.2181	0.4516
470	0.1484	0.3148
768	0.0575	0.1139

19 November 1979 (Day 323)

Load (kN):	20.5	43.1
Radius (mm)	Displacement (mm)	
146	0.5321	0.9728
295	0.2794	0.5791
394	0.2012	0.4191
476	0.1539	0.3150
772	0.0632	0.1331

Pavement and Subgrade Temperatures (°C)

Depth (mm)	30 Oct	12 Feb	7 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	7 May	29 May	24 July	27 Sep	19 Nov
Surface	15.2	--	3.1	0.5	19.9	8.0	7.2	36.7	32.7	39.9	31.3	--	--
50		--	2.9	0.6	0.3	9.0	6.8	33.4	33.5	34.8	32.0	--	--
210		-3.6	0.8	0.1	2.2	2.4	3.3	16.1	21.1	20.8	31.4	--	--
340		-3.1	0.0	1.5	1.5	1.7	2.9	11.9	17.7	17.5	31.1	--	--
410		-2.4	0.0	0.0	1.0	1.2	2.8	11.1	17.0	16.9	30.8	--	--
450		-1.0	0.0	0.0	0.5	0.6	3.0	10.3	16.3	16.6	30.1	--	--
610		0.2	0.0	0.0	0.1	0.2	3.2	9.6	15.4	16.1	28.6	--	--
690		0.7	0.1	0.1	0.0	0.1	3.2	8.9	14.7	15.7	27.5	--	--
840		1.4	0.6	0.5	0.0	0.8	3.3	7.9	13.4	15.1	25.5	--	--
1060		2.4	1.4	1.1	0.0	1.6	3.3	6.8	12.0	14.2	23.5	--	--
1260		3.2	2.1	1.6	0.4	1.8	3.3	6.1	10.9	14.1	21.9	--	--
1460		4.0	3.1	2.3	2.1	2.3	3.6	5.9	10.1	13.0	20.8	--	--

Moisture Tension (kPa)

Depth (mm)	12 Feb	7 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	7 May	29 May	24 July	27 Sep	19 Nov
457	9.8	0	1.9	6.9	6.4	6.9	5.4	8.3	7.9	12.0	10.0	10.0
559	7.8	1.0	2.9	3.9	3.9	3.9	8.8	4.9	4.9	10.0	6.5	10.0

Table A2. Data from repeated-load plate-bearing (RPB) tests, Graves sand test section.

Resilient Displacement at Two Load Levels

30 October 1978 (Day-63)

Load (kN):	18.9	
Radius (mm)	Displacement (mm)	
140	0.7836	not done
190	0.3708	
394	0.2116	
444	0.1374	
749	0.0414	

12 February 1979 (Day 43)

Load (kN):	19.8	39.6
Radius (mm)	Displacement (mm)	
137	0.0605	0.1236
308	0.0194	0.0361
384	0.0139	0.0291
464	0.0120	0.0260
762	0.0136	0.0230

6 March 1979 (Day 65)

Load (kN):	7.3	18.2
Radius (mm)	Displacement (mm)	
143	0.4735	1.0693
289	0.2258	0.5484
372	0.1456	0.3675
454	0.0860	0.1803
749	--	--

13 March 1979 (Day 72)

Load (kN):	19.1	41.1
Radius (mm)	Displacement (mm)	
133	0.550	1.276
289	0.648	1.435
368	0.206	0.438
451	0.154	0.347
753	0.036	0.064

21 March 1979 (Day 80)

Load (kN):	19.6	36.7
Radius (mm)	Displacement (mm)	
137	0.860	1.551
286	0.464	0.762
365	0.261	0.458
451	0.150	0.225
737	0.036	0.062

28 March 1979 (Day 87)

Load (kN):	19.5	40.0
Radius (mm)	Displacement (mm)	
140	0.750	1.730
295	0.434	0.965
384	0.295	0.474
470	0.175	0.423
765	0.034	0.082

4 April 1979 (Day 94)

Load (kN):	18.5	38.9
Radius (mm)	Displacement (mm)	
136	0.8062	1.6423
289	0.4166	0.9144
368	0.3097	0.6548
457	0.1955	0.4243
752	0.0496	0.0834

24 April 1979 (Day 114)

Load (kN):	18.7	39.1
Radius (mm)	Displacement (mm)	
143	0.7296	1.5851
298	0.3505	0.7620
384	0.2129	0.4774
476	0.1304	0.2982
765	0.0451	0.1038

8 May 1979 (Day 128)

Load (kN):	19.1	40.0
Radius (mm)	Displacement (mm)	
140	0.7992	1.5989
276	0.3861	0.8319
378	0.2194	0.4774
467	0.1345	0.2912
759	0.0541	0.0925

30 May 1979 (Day 150)

Load (kN):	21.6	40.7
Radius (mm)	Displacement (mm)	
143	0.7397	1.5182
279	0.3785	0.8026
381	0.2129	0.4865
467	0.1345	0.3120
768	0.0586	0.0970

25 July 1979 (Day 206)

Load (kN):	20.7	42.5
Radius (mm)	Displacement (mm)	
143	0.7261	1.4440
270	0.3708	0.8065
381	0.1716	0.3806
467	0.1123	0.2441
759	0.0440	0.0902

27 September 1979 (Day 270)

Load (kN):	20.9	43.4
Radius (mm)	Displacement (mm)	
146	0.6337	1.3130
289	0.3073	1.1049
384	0.2052	0.4387
473	0.1373	0.3259
765	0.0474	0.0857

19 November 1979 (Day 323)

Load (kN):	20.2	43.1
Radius (mm)	Displacement (mm)	
143	0.6236	1.2129
314	0.2997	0.6248
403	0.2090	0.4420
483	0.1499	0.3226
794	0.0462	0.1036

Pavement and Subgrade Temperatures (°C)

Depth (mm)	30 Oct	12 Feb	6 Mar	13 Mar	21 Mar	28 Mar	4 Apr	24 Apr	8 May	30 May	25 July	27 Sep	19 Nov
Surface	12.3	-7.4	5.5	-1.1	3.9	-1.1	1.0	13.5	14.3	15.9	26.9	12.2	7.1
51		-10.1	4.1	-0.4	4.0	-0.8	1.0	14.7	18.2	17.7	28.2	12.2	5.6
152		-8.7	1.5	0.2	2.6	0.1	0.2	11.5	17.0	18.4	28.8	14.7	5.3
305		-4.4	-0.4	0.0	0.4	0.6	0.8	11.6	17.6	19.1	29.6	18.4	6.3
457		-0.5	-0.4	0.0	-0.4	-0.3	0.4	10.5	16.1	18.2	28.5	19.0	7.3
610		0.5	-0.4	0.0	-0.4	-0.9	-0.4	9.0	14.5	17.1	26.9	18.8	7.8
762		1.4	0.1	0.3	-0.1	--	0.1	7.3	12.7	15.8	25.1	18.5	8.3
914		1.7	0.5	0.7	0.4	--	0.3	6.4	11.6	15.1	23.6	18.5	9.0
1067		2.2	1.4	1.1	0.7	--	0.6	5.7	10.9	14.6	22.5	18.5	9.3
1219		2.4	1.7	1.4	1.1	--	1.1	5.1	10.0	14.2	21.1	18.5	9.8
1371		2.8	2.1	1.8	1.4	--	1.4	4.9	9.5	13.7	20.3	18.5	10.2
1524		3.2	--	2.1	1.7	--	1.7	4.7	9.0	13.4	19.5	18.3	10.5

Moisture Tension (kPa)

Depth (mm)	12 Feb	6 Mar	13 Mar	21 Mar	28 Mar	4 Apr	24 Apr	8 May	30 May	25 July	27 Sep	19 Nov
152	1.9	0	4.4	5.4	6.8	7.8	11.8	11.8	9.8	14.0	10.5	12.0
305	11.8	0	3.9	5.9	6.4	7.8	11.8	11.8	9.8	14.5	12.0	10.0
610	12.3	0	7.8	7.4	5.9	6.9	9.8	9.8	8.3	12.0	10.0	--
914	3.9	1.9	0	1.9	0	0	2.5	2.8	0	3.5	1.5	--

Table A3. Data from repeated-load plate-bearing (RPB) tests, Hart Brothers sand test section.

Resilient Displacement at Two Load Levels

30 October 1978 (Day-63)

Load (kN):	17.8	37.8
Radius (mm)	Displacement (mm)	
140	0.6515	1.1989
305	0.2616	0.4902
387	0.1526	0.3073
457	0.1110	0.2068
762	0.0419	0.0853

13 February 1979 (Day 43)

Load (kN):	20	37.4
Radius (mm)	Displacement (mm)	
127	0.0946	0.0934
286	0.0032	0.0194
362	0.0021	0.0140
445	0.002	0.0100
730	--	0.0063

6 March 1979 (Day 65)

Load (kN):	18.7	40.5
Radius (mm)	Displacement (mm)	
137	0.6349	1.2391
289	0.2903	0.4516
368	0.1456	0.1976
457	0.0490	0.0500
759	0.0089	0.0262

13 March 1979 (Day 72)

Load (kN):	19.8	41.8
Radius (mm)	Displacement (mm)	
146	0.554	1.003
305	0.559	1.016
400	0.135	0.271
483	0.087	0.170
791	0.023	0.046

21 March 1979 (Day 80)

Load (kN):	18.9	40.0
Radius (mm)	Displacement (mm)	
146	0.671	1.297
299	0.279	0.616
384	0.159	0.329
470	0.094	0.182
768	0.023	0.052

28 March 1979 (Day 87)

Load (kN):	19.3	40.5
Radius (mm)	Displacement (mm)	
143	0.688	1.370
302	0.371	0.705
391	0.222	0.468
479	0.137	0.261
679	0.112	0.088

4 April 1979 (Day 94)

Load (kN):	18.5	41.4
Radius (mm)	Displacement (mm)	
143	0.7005	1.3531
298	0.3556	0.7366
384	0.2155	0.4613
470	0.1304	0.2857
762	0.0496	0.1116

24 April 1979 (Day 114)

Load (kN):	19.3	40.3
Radius (mm)	Displacement (mm)	
137	0.6839	1.2684
289	0.3277	0.6553
375	0.1942	0.3923
460	0.1165	0.2510
759	0.0508	0.0958

7 May 1979 (Day 127)

Load (kN):	18.9	40.0
Radius (mm)	Displacement (mm)	
139	0.7224	1.3497
283	0.2794	0.5639
375	0.1561	0.3096
470	0.1095	0.2094
756	0.0496	0.0981

29 May 1979 (Day 149)

Load (kN):	18.9	40.9
Radius (mm)	Displacement (mm)	
146	0.6836	1.3179
289	0.2692	0.5512
394	0.1510	0.3058
476	0.1096	0.2205
775	0.0474	0.0947

25 July 1979 (Day 206)

Load (kN):	20.7	42.4
Radius (mm)	Displacement (mm)	
140	0.7050	1.2690
270	0.3480	0.6706
375	0.1613	0.3135
457	0.1068	0.2108
768	0.0451	0.0902

27 September 1979 (Day 270)

Load (kN):	20.2	42.7
Radius (mm)	Displacement (mm)	
146	0.6126	1.1802
318	0.2388	0.5309
397	0.1523	0.3226
492	0.1026	0.2122
784	0.0406	0.0891

20 November 1979 (Day 324)

Load (kN):	20.0	42.7
Radius (mm)	Displacement (mm)	
146	0.5220	0.9931
305	0.2743	0.5486
400	0.1910	0.3861
486	0.1387	0.2896
784	0.0472	0.1105

Pavement and Subgrade Temperatures (°C)

Depth (mm)	30 Oct	13 Feb	6 Mar	13 Mar	21 Mar	28 Mar	4 Apr	24 Apr	7 May	29 May	25 July	27 Sep	20 Nov
Surface	20.9	-6.8	7.0	1.0	9.3	-0.4	7.7	19.5	44.9	33.4	29.1	13.1	6.7
51		-7.9	5.1	-0.1	8.3	-0.5	5.4	19.5	36.3	33.6	30.2	13.7	4.8
152		-9.1	2.9	-0.2	5.6	0.4	1.7	13.9	29.3	27.9	29.1	14.7	4.8
305		-7.2	0.0	-0.1	2.9	1.0	1.2	11.4	20.7	20.9	28.3	16.4	5.0
457		-4.9	-0.2	-0.1	1.5	1.5	1.7	11.8	16.9	17.5	28.7	18.6	6.2
610		-2.5	-0.2	-0.2	0.0	0.9	1.4	10.8	15.5	16.6	27.8	18.9	6.9
762		-1.0	-0.1	-0.2	0.0	0.0	1.0	9.6	14.5	16.2	26.5	18.8	7.4
914		0.0	-0.1	-0.3	0.0	-0.7	0.6	8.3	13.5	15.7	25.1	18.5	7.9
1067		0.5	0.0	-0.2	-0.1	-0.7	0.5	7.5	12.7	15.2	23.9	18.4	8.2
1219		1.2	0.2	0.0	0.2	-0.4	0.7	6.7	11.9	14.8	22.9	18.3	8.7
1371		1.7	0.6	0.4	0.6	0.0	1.0	6.3	11.1	14.4	21.8	18.3	9.1
1524		1.7	2.0	0.8	0.9	0.4	1.2	5.8	10.6	14.1	21.0	18.3	9.3

Moisture Tension (kPa)

Depth (mm)	13 Feb	6 Mar	13 Mar	21 Mar	28 Mar	4 Apr	24 Apr	7 May	29 May	25 July	27 Sep	20 Nov
152	5.9	0	5.9	5.4	7.9	6.4	9.8	7.9	6.9	12.5	10.0	10.0
305	1.9	0	4.4	8.3	7.4	7.4	10.3	9.8	7.4	13.0	10.0	10.0
610	1.9	8.8	1.4	3.4	4.9	6.9	9.8	9.8	7.4	11.0	8.4	10.0
914	9.8	10.8	0	1.0	1.0	2.4	4.9	4.4	3.9	6.5	5.0	13.0

Table A4. Data from repeated-load plate-bearing (RPB) tests, Hyannis sand test section.

Resilient Displacements at Two Load Levels

31 October 1978 (Day-63)

Load (kN):	15.6	38.9
Radius (mm)	Displacement (mm)	
140	0.4699	0.8966
292	0.3073	0.5969
362	0.2233	0.4572
432	0.1788	0.3667
743	0.0571	0.1229

12 February 1979 (Day 43)

Load (kN):	20	40.0
Radius (mm)	Displacement (mm)	
143	0.0772	0.1095
299	0.0097	0.0174
378	0.0090	0.0148
457	0.0080	0.0117
749	0.0010	0.0126

7 March 1979 (Day 66)

Load (kN):	19.1	41.4
Radius (mm)	Displacement (mm)	
140	0.6915	1.7930
292	0.4290	1.2322
378	0.3120	0.9499
467	0.223	0.7420
756	--	--

12 March 1979 (Day 71)

Load (kN):	19.8	41.8
Radius (mm)	Displacement (mm)	
133	0.458	1.029
276	0.552	1.340
368	0.175	0.500
445	0.129	0.419
753	0.029	0.125

20 March 1979 (Day 79)

Load (kN):	19.1	40.0
Radius (mm)	Displacement (mm)	
137	0.425	0.839
283	0.244	0.521
375	0.168	0.297
457	0.108	0.197
753	0.024	0.045

27 March 1979 (Day 86)

Load (kN):	19.1	40.0
Radius (mm)	Displacement (mm)	
140	0.423	0.874
286	0.267	0.579
378	0.196	0.342
464	0.136	0.283
749	0.051	0.106

3 April 1979 (Day 93)

Load (kN):	18.2	40.3
Radius (mm)	Displacement (mm)	
140	0.4029	0.8800
292	0.2616	0.5740
375	0.1948	0.4181
470	0.1387	0.3120
762	0.0451	0.1150

23 April 1979 (Day 113)

Load (kN):	18.9	39.6 7
Radius (mm)	Displacement (mm)	
143	0.5609	1.1734
286	0.2743	0.5969
381	0.1729	0.3626
467	0.1206	0.2496
759	0.0496	0.0947

7 May 1979 (Day 127)

Load (kN):	19.6	39.4
Radius (mm)	Displacement (mm)	
146	0.6202	1.1697
302	0.2464	0.4902
391	0.1497	0.3032
476	0.1068	0.2136
772	0.0439	0.0879

29 May 1979 (Day 149)

Load (kN):	19.8	40.7
Radius (mm)	Displacement (mm)	
133	0.5992	1.3087
267	0.3150	0.6248
365	0.1884	0.3794
448	0.1276	0.2552
752	0.0496	0.1026

24 July 1979 (Day 205)

Load (kN):	19.8	42.3
Radius (mm)	Displacement (mm)	
143	0.5217	1.0860
283	0.2413	0.4826
387	0.1394	0.2955
473	0.0985	0.2025
765	0.0361	0.0846

27 September 1979 (Day 270)

Load (kN):	20.5	43.6
Radius (mm)	Displacement (mm)	
143	0.5883	1.0991
286	0.2870	0.5652
378	0.1884	0.3484
470	0.1234	0.2593
759	0.0530	0.0992

19 November 1979 (Day 323)

Load (kN):	20.0	43.1
Radius (mm)	Displacement (mm)	
146	0.4013	0.8242
289	0.2667	0.5359
394	0.1859	0.3734
476	0.1359	0.2819
772	0.0541	0.1173

Pavement and Subgrade Temperatures (°C)

Depth (mm)	31 Oct	12 Feb	7 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	7 May	29 May	24 July	27 Sep	19 Nov
Surface	4.6	-9.4	none	6.3	23.5	7.1	6.7	27.6	33.7	31.9	34.9	27.6	6.4
51		-8.7	none	4.0	19.0	9.1	6.5	29.2	36.0	33.5	35.7	29.3	8.0
152		-10.3	none	-1.8	10.3	0.6	5.1	18.1	20.0	20.0	27.6	20.2	6.1
305		-7.1	none	-0.1	4.9	3.5	2.0	17.7	22.9	21.3	31.3	21.0	7.8
457		-5.5	none	-0.4	0.6	2.0	1.7	11.6	17.5	17.5	29.7	18.7	6.9
610		-3.9	none	-0.4	-0.2	1.4	1.3	9.6	18.6	16.7	28.5	18.8	7.2
762		-1.4	none	-0.5	-0.2	0.5	0.8	8.3	14.3	16.1	26.8	18.8	7.8
914		-0.5	none	-0.2	-0.2	0.0	0.4	7.2	13.1	15.4	25.3	18.8	8.3
1067		0.1	none	-0.1	0.0	0.1	0.4	6.4	12.0	14.8	23.9	18.8	8.8
1219		0.5	none	0.3	0.4	0.4	0.7	5.7	11.1	14.2	22.9	18.8	9.2
1371		--	none	0.6	0.8	0.8	1.1	5.0	10.3	13.7	21.7	18.7	9.6
1524		--	none	1.0	1.1	1.1	1.4	4.6	9.6	13.2	20.8	18.6	10.0

Moisture Tension (kPa)

Depth (mm)	12 Feb	7 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	7 May	29 May	24 July	27 Sep	19 Nov
559	64	3	3	6	4.4	4	7.8	6.8	6	6.0	4.5	12.0
711	7.8	8	7.8	7.8	8	8	6	7.4	4	8.0	3.0	--

Table A5. Data from repeated-load plate-bearing (RPB) tests, dense-graded stone test section.

Resilient Displacement at Two Load Levels

31 October 1978 (Day-63)

Load (kN):	18.9	40.0
Radius (mm)	Displacement (mm)	
146	0.3810	0.6362
298	0.1872	0.3912
368	0.1387	0.2769
444	0.0105	0.2329
743	0.0361	0.0836

12 February 1979 (Day 43)

Load (kN):	19.3	40.5
Radius (mm)	Displacement (mm)	
140	0.0648	0.0873
289	0.0135	0.0181
375	0.0076	0.0128
449	0.0062	0.0120
740	0.0062	0.0115

7 March 1979 (Day 66)

Load (kN):	19.6	41.8
Radius (mm)	Displacement (mm)	
140	0.3854	0.7234
292	0.2323	0.5032
381	0.1803	0.3640
464	0.137	0.2740
759	--	--

12 March 1979 (Day 71)

Load (kN):	20	42.2
Radius (mm)	Displacement (mm)	
146	0.408	0.791
305	0.508	1.048
394	0.164	0.355
470	0.139	0.291
787	0.044	0.085

20 March 1979 (Day 79)

Load (kN):	19.1	40.9
Radius (mm)	Displacement (mm)	
137	0.394	0.760
276	0.282	0.551
375	0.187	0.386
457	0.140	0.280
756	0.037	0.103

27 March 1979 (Day 86)

Load (kN):	19.1	40.0
Radius (mm)	Displacement (mm)	
137	0.384	0.720
289	0.254	0.477
378	0.183	0.341
464	0.129	0.244
753	0.059	0.091

3 April 1979 (Day 93)

Load (kN):	18.2	40.4
Radius (mm)	Displacement (mm)	
136	0.3300	0.6499
276	0.2464	0.4724
362	0.1832	0.3613
451	0.1262	0.2677
746	0.0451	0.1105

23 April 1979 (Day 113)

Load (kN):	18.5	40.5
Radius (mm)	Displacement (mm)	
143	0.4285	0.8739
295	0.2108	0.4242
384	0.1368	0.2709
470	0.0887	0.1719
765	0.0384	0.0620

7 May 1979 (Day 127)

Load (kN):	19.3	40.5
Radius (mm)	Displacement (mm)	
146	0.4367	0.8632
292	0.2006	0.4115
387	0.1123	0.2477
497	0.0766	0.1636
772	0.0361	0.0789

29 May 1979 (Day 149)

Load (kN):	18.9	41.1
Radius (mm)	Displacement (mm)	
143	0.4370	0.8616
286	0.2210	0.4470
387	0.1316	0.2723
470	0.0874	0.1844
775	0.0361	0.0761

24 July 1979 (Day 205)

Load (kN):	20.0	42.5
Radius (mm)	Displacement (mm)	
146	0.4679	0.9092
279	0.2032	0.3835
394	0.1058	0.2090
489	0.0790	0.1539
781	0.0395	0.0710

27 September 1979 (Day 270)

Load (kN):	20.2	43.6
Radius (mm)	Displacement (mm)	
149	0.3732	0.7423
286	0.2007	0.4089
381	0.1290	0.2426
470	0.0915	0.1831
768	0.0383	0.0677

19 November 1979 (Day 323)

Load (kN):	20.0	43.6
Radius (mm)	Displacement (mm)	
149	0.3404	0.6363
308	0.1880	0.3759
410	0.1240	0.2743
486	0.0942	0.2080
791	0.0282	0.1016

Pavement and Subgrade Temperatures (°C)

Depth (mm)	31 Oct	12 Feb	7 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	7 May	29 May	24 July	27 Sep	19 Nov
Surface	7.2	-6.8	4.5	6.1	21.1	12.0	8.6	28.8	33.8	32.3	40.0	31.2	8.3
51		-8.6	--	4.4	20.5	14.6	8.4	31.3	36.7	33.8	41.9	29.1	9.5
152		--	--	--	--	--	--	--	--	--	--	--	--
305		--	--	-0.4	2.9	5.7	4.1	15.6	20.8	20.6	31.0	20.1	7.0
457		-6.1	--	-0.3	1.4	4.4	3.7	11.2	16.9	17.2	29.4	18.4	6.6
610		-1.9	--	-0.3	0.4	4.2	3.6	9.4	15.0	16.2	28.2	18.4	7.0
762		-1.3	-0.4	-0.2	-0.4	3.7	3.4	8.2	13.7	15.4	26.6	18.5	7.7
914		-0.2	-0.2	-0.1	-0.4	2.9	3.2	7.0	12.4	14.7	25.1	18.5	8.1
1067		0.4	-0.3	0.4	-0.1	2.3	2.9	6.1	11.2	14.0	23.7	18.4	8.5
1219		1.0	0.0	0.7	0.4	1.7	2.5	5.0	10.0	13.2	22.5	18.5	9.0
1371		1.4	0.3	1.1	0.8	1.5	2.4	4.3	9.0	12.7	21.3	18.4	9.5
1524		1.7	0.5	1.1	1.0	1.6	2.3	4.0	8.4	12.1	20.6	18.4	9.8

Moisture Tension (kPa)

Depth (mm)	12 Feb	7 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	7 May	29 May	24 July	27 Sep	19 Nov
559	43.0	0	0	0	0	0	5.9	0	4.9	6.0	5.0	--
711	24.5	0	0	0	0	0	0	0	3.4	4.0	3.5	--

Table A6. Data from repeated-load plate-bearing (RPB) tests, Sibley till test section.

Resilient Displacement at Two Load Levels

30 October 1978 (Day-63)

Load (kN):	34.5	
Radius (mm)	**Displacement (mm)**	
140	1.1735	not done
298	0.5994	
349	0.3429	
447	0.2043	
743	0.0312	

12 February 1979 (Day 43)

Load (kN):	19.8	41.4
Radius (mm)	**Displacement (mm)**	
140	0.1087	0.1715
298	0.0077	0.0148
378	0.0049	0.0125
457	0.0030	0.009
768	0.0026	0.0105

6 March 1979 (Day 65)

Load (kN):	18.7	38.7
Radius (mm)	**Displacement (mm)**	
133	1.6178	2.3425
286	0.9290	1.2258
372	0.5894	0.5617
454	0.3180	0.2770
746	0.1936	0.3663

12 March 1979 (Day 71)

Load (kN):	19.6	38.9
Radius (mm)	**Displacement (mm)**	
140	0.824	1.587
282	0.813	1.461
378	0.242	0.413
467	0.128	0.270
756	0.025	0.032

20 March 1979 (Day 79)

Load (kN):	19.3	39.8
Radius (mm)	**Displacement (mm)**	
143	0.924	1.663
305	0.414	0.756
387	0.196	0.409
467	0.128	0.229
768	0.014	0.023

27 March 1979 (Day 86)

Load (kN):	18.0	40.0
Radius (mm)	**Displacement (mm)**	
140	0.685	1.320
286	0.363	0.696
381	0.186	0.414
470	0.114	0.238
756	0.036	0.069

3 April 1979 (Day 93)

Load (kN):	18.7	41.1
Radius (mm)	**Displacement (mm)**	
136	0.5986	1.1698
279	0.2921	0.6883
359	0.1935	0.4581
451	0.1123	0.2759
749	0.0327	0.0676

23 April 1979 (Day 113)

Load (kN):	18.9	39.4
Radius (mm)	**Displacement (mm)**	
143	0.5987	1.2120
298	0.1829	0.4394
390	0.0980	0.2335
476	0.0585	0.1414
775	0.0191	0.0439

8 May 1979 (Day 128)

Load (kN):	19.8	40.9
Radius (mm)	**Displacement (mm)**	
133	0.4609	0.9761
270	0.2032	0.4724
352	0.0955	0.2426
441	0.0513	0.1289
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30 May 1979 (Day 150)

Load (kN):	19.1	41.4
Radius (mm)	**Displacement (mm)**	
140	0.4762	0.9832
289	0.2159	0.4902
369	0.1032	0.2723
460	0.0679	0.1470
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24 July 1979 (Day 206)

Load (kN):	20.5	43.1
Radius (mm)	**Displacement (mm)**	
140	0.5178	1.0145
279	0.1372	0.2946
387	0.0735	0.1613
473	0.0527	0.1165
765	0.0214	0.0372

27 September 1979 (Day 270)

Load (kN):	20.7	43.6
Radius (mm)	**Displacement (mm)**	
140	0.5145	1.0755
283	0.1803	0.4039
365	0.6877	0.2387
454	0.0416	0.1260
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19 November 1979 (Day 323)

Load (kN):	20.0	43.1
Radius (mm)	**Displacement (mm)**	
149	0.4470	0.8725
308	0.1829	0.3962
403	0.1110	0.2565
489	0.0749	0.1775
683	0.0226	0.0541

Pavement and Subgrade Temperatures (°C)

Depth (mm)	30 Oct	12 Feb	6 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	8 May	30 May	24 July	27 Sep	19 Nov
Surface	12.5	3.7	8.4	10.5	--	15.1	8.3	--	23.5	--	39.6	--	--
50		-2.6	5.4	6.6	9.5	1.3	7.8	18.3	18.7	15.7	--	--	--
230		-8.5	2.4	0.2	--	2.1	2.8	18.9	18.0	19.1	31.3	--	--
330		-7.1	0.5	0.3	0.1	3.2	3.1	14.5	18.3	19.4	29.0	--	--
410		-5.7	0.1	0.2	0.1	3.8	3.5	12.3	17.8	19.1	28.1	--	--
520		-4.2	-0.1	0.2	0.4	4.1	3.6	10.4	16.9	18.4	27.4	--	--
600		-3.3	-0.1	0.2	0.8	4.2	3.7	9.7	16.2	18.0	26.0	--	--
680		-2.6	-0.1	0.1	1.2	4.2	3.7	9.2	15.5	17.4	25.7	--	--
830		-1.5	-0.1	0.0	1.6	4.2	3.8	8.4	14.3	15.6	22.9	--	--
1090		0.0	0.0	0.1	2.2	4.7	4.1	7.1	12.5	15.2	24.4	--	--
1330		0.7	0.3	0.3	4.0	--	5.1	6.1	11.2	14.9	20.9	--	--
		--	--	--	--	--	--	--	--	--	--	--	--

Moisture Tension (kPa)

Depth (mm)	12 Feb	6 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	8 May	30 May	24 July	27 Sep	19 Nov
152	7.4	0	24.5	4.4	5.8	--	7.3	9.3	5.4	12.0	4.5	--
305	86.2	0	0	3.9	4.9	--	6.4	7.3	6.8	0	4.5	--
559	--	--	--	--	--	3.9	--	--	--	--	--	--
610	1.0	6.8	0	0.5(leak)	2.9	--	6.8	3.4	2.9	6.0	4.0	--
711	--	--	--	--	--	8.3	--	--	--	--	--	--
914	1.0	49.0	7.8	5.4	4.9	--	6.4	5.8	5.4	8.0	6.5	--

Table A7. Data from falling-weight deflectometer tests, Ikalanian sand test section.

Resilient Displacement at Two Load Levels

25 February 1980 (Day 56)

Drop Height (mm):	40	219
Pressure (kPa):	275	583
Radius (mm)	Displacement (μm)	
0	167	425
200	151	414
400	106	275
800	50	135
1500	21	52

12 March 1980 (Day 72)

Drop Height (mm):	50	200
Pressure (kPa):	237	544
Radius (mm)	Displacement (μm)	
0	311	1524
300	285	1026
525	178	479
750	129	261
1050	73	144

19 March 1980 (Day 79)

Drop Height (mm):	50	100
Pressure (kPa):	273	363
Radius (mm)	Displacement (μm)	
0	795	1146
300	420	606
525	233	339
750	144	202
1050	76	105

22 March 1980 (Day 82)

Drop Height (mm):	50	100
Pressure (kPa):	207	319
Radius (mm)	Displacement (μm)	
0	593	1151
300	467	736
525	273	401
750	155	217
1050	89	121

26 March 1980 (Day 86)

Drop Height (mm):	50	100
Pressure (kPa):	253	358
Radius (mm)	Displacement (μm)	
0	770	1156
300	415	594
525	244	344
750	156	227
1050	84	119

29 March 1980 (Day 89)

Drop Height (mm):	50	100
Pressure (kPa):	253	350
Radius (mm)	Displacement (μm)	
0	738	1069
300	413	582
525	203	287
750	127	178
1050	78	108

3 April 1980 (Day 94)

Drop Height (mm):	50	100
Pressure (kPa):	248	355
Radius (mm)	Displacement (μm)	
0	834	1229
300	441	635
525	198	281
750	119	173
1050	71	102

10 April 1980 (Day 101)

Drop Height (mm):	50	100
Pressure (kPa):	230	332
Radius (mm)	Displacement (μm)	
0	784	1121
300	416	592
525	224	319
750	126	181
1050	80	111

17 April 1980 (Day 108)

Drop Height (mm):	50	100
Pressure (kPa):	270	370
Radius (mm)	Displacement (μm)	
0	842	1189
300	447	659
525	199	277
750	122	171
1050	74	102

Pavement and Subgrade Temperature (°C)

Depth (mm)	25 Feb	12 Mar	22 Mar	26 Mar
Surface	11.3	14.3	4.4	13.1
50	8.0	11.7	4.4	12.7
210	-0.6	0.0	0.9	3.6
340	-0.6	-0.1	1.4	3.7
410	-0.4	0.0	1.4	3.7
450	-0.3	0.3	1.6	3.7
610	-0.2	0.8	1.6	3.4
690	0.3	1.1	1.5	3.2
840	1.2	1.8	1.6	2.8
1060	1.8	2.6	2.0	2.6
1260	2.7	3.3	2.4	2.6
1460	3.7	4.4	3.3	3.1

Moisture Tension

No data

Table A8. Data from falling-weight deflectometer tests, Graves sand test section.

Resilient Displacement at Two Load Levels

25 February 1980 (Day 56)

Drop Height (mm):	36	200
Pressure (kPa):	261	566
Radius (mm)	Displacement	(μm)
0	126	332
200	126	345
400	81	211
800	35	100
1500	16	40

12 March 1980 (Day 72)

Drop Height (mm):	50	200
Pressure (kPa):	250	550
Radius (mm)	Displacement	(μm)
0	392	1411
300	388	940
525	189	446
750	116	230
1050	61	116

19 March 1980 (Day 79)

Drop Height (mm):	50	
Pressure (kPa):	267	
Radius (mm)	Displacement	(μm)
0	1054	
300	522	
525	217	
750	110	
1050	67	

22 March 1980 (Day 82)

Drop Height (mm):	50	
Pressure (kPa):	185	
Radius (mm)	Displacement	(μm)
0	942	
300	581	
525	304	
750	139	
1050	88	

26 March 1980 (Day 86)

Drop Height (mm):	50	
Pressure (kPa):	238	
Radius (mm)	Displacement	(μm)
0	1308	
300	522	
525	263	
750	146	
1050	75	

29 March 1980 (Day 89)

Drop Height (mm):	25	50
Pressure (kPa):	159	240
Radius (mm)	Displacement	(μm)
0	551	989
300	341	547
525	174	260
750	95	134
1050	54	73

3 April 1980 (Day 94)

Drop Height (mm):	25	50
Pressure (kPa):	200	255
Radius (mm)	Displacement	(μm)
0	774	1013
300	362	461
525	162	208
750	98	123
1050	65	80

10 April 1980 (Day 101)

Drop Height (mm):	50	100
Pressure (kPa):	235	334
Radius (mm)	Displacement	(μm)
0	972	1352
300	579	845
525	287	409
750	110	169
1050	70	98

17 April 1980 (Day 108)

Drop Height (mm):	50	100
Pressure (kPa):	230	322
Radius (mm)	Displacement	(μm)
0	940	1335
300	538	792
525	247	357
750	106	143
1050	72	96

Pavement and Subgrade Temperatures (°C)

Depth (mm)	25 Feb	12 Mar	19 Mar	26 Mar	29 Mar	3 Apr	10 Apr	17 Apr
Surface	-0.6	11.8	18.2	13.7	11.3	18.9	13.6	15.8
51	0.1	2.1	1.7	4.9	8.1	10.5	10.7	12.9
152	-0.3	0.0	-0.1	2.1	6.6	4.2	8.6	7.1
305	-0.1	-0.1	-0.2	1.4	5.7	3.4	7.1	7.1
457	0.3	0.2	0.1	1.2	4.2	3.8	6.2	8.2
610	0.8	0.6	0.4	1.3	3.3	3.7	5.6	8.0
762	1.3	1.1	0.8	1.1	2.3	3.1	4.8	7.3
914	1.8	1.6	1.2	1.2	2.0	2.8	4.4	6.6
1067	2.3	1.9	1.6	1.4	1.9	2.6	4.0	6.1
1219	2.8	2.4	2.0	1.6	2.0	2.4	3.7	5.4
1371	3.2	2.8	2.3	1.9	2.1	2.4	3.5	5.1
1524	3.5	3.0	2.5	2.1	2.3	2.4	3.4	4.9

Moisture Tension (kPa)

Depth (mm)	25 Feb	12 Mar	19 Mar	22 Mar	26 Mar	29 Mar	3 Apr	10 Apr	17 Apr
152	3.0	0	0	0	5.0	6.0	7.0	4.0	10.0
305	16.5	0.5	2.0	0	7.0	7.0	8.0	5.5	10.0
610	11.5	9.0	7.0	5.0	5.0	7.0	7.5	4.0	8.0
914	2.0	0	0	0	0	0	0.5	0	0

Table A9. Data from falling-weight deflectometer tests, Hart Brothers sand test section.

Resilient Displacement at Two Load Levels

25 February 1980 (Day 56)

Drop Height (mm):	36	200
Pressure (kPa):	279	605
Radius (mm)	Displacement (μm)	
0	74	197
200	67	169
400	29	84
800	16	47
1500	11	26

12 March 1980 (Day 72)

Drop Height (mm):	50	200
Pressure (kPa):	255	599
Radius (mm)	Displacement (μm)	
0	273	1039
300	146	358
600	79	149
1050	34	73
1350	27	55

19 March 1980 (Day 79)

Drop Height (mm):	50	100
Pressure (kPa):	266	382
Radius (mm)	Displacement (μm)	
0	696	1115
300	322	467
525	129	176
750	77	106
1050	56	77

22 March 1980 (Day 82)

Drop Height (mm):	50	100
Pressure (kPa):	197	352
Radius (mm)	Displacement (μm)	
0	395	1035
300	341	605
525	186	273
750	116	154
1050	66	89

26 March 1980 (Day 86)

Drop Height (mm):	50	150
Pressure (kPa):	240	414
Radius (mm)	Displacement (μm)	
0	805	1384
300	386	183
525	188	100
750	110	184
1050	61	97

29 March 1980 (Day 89)

Drop Height (mm):	50	100
Pressure (kPa):	262	360
Radius (mm)	Displacement (μm)	
0	832	1133
300	492	635
525	189	262
750	110	153
1050	65	87

3 April 1980 (Day 94)

Drop Height (mm):	50	100
Pressure (kPa):	252	351
Radius (mm)	Displacement (μm)	
0	785	1075
300	409	564
525	168	237
750	97	139
1050	57	80

10 April 1980 (Day 101)

Drop Height (mm):	50	100
Pressure (kPa):	247	354
Radius (mm)	Displacement (μm)	
0	823	1130
300	446	599
525	178	250
750	105	147
1050	63	88

17 April 1980 (Day 108)

Drop Height (mm):	50	100
Pressure (kPa):	238	331
Radius (mm)	Displacement (μm)	
0	803	1086
300	414	563
525	176	240
750	100	140
1050	61	82

Pavement and Subgrade Temperature (°C)

Depth (mm)	25 Feb	12 Mar	19 Mar	26 Mar	29 Mar	3 Apr	10 Apr	17 Apr
Surface	0.3	14.3	16.8	11.3	9.0	12.2	13.2	16.8
51	0.4	1.1	4.5	6.7	7.9	11.1	10.8	12.5
152	-0.6	0.0	0.1	3.0	6.4	4.3	8.8	6.9
305	-0.5	0.0	-0.1	1.4	4.8	2.4	7.7	6.1
457	-0.2	0.0	-0.1	1.2	4.4	3.2	6.7	7.7
610	-0.2	-0.1	-0.1	0.5	3.1	3.3	5.9	8.3
762	0.0	0.0	-0.1	-0.1	2.1	2.9	5.3	8.1
914	0.3	0.2	0.1	0.1	1.3	2.5	4.7	7.6
1067	0.7	0.6	0.4	0.4	1.1	2.2	4.2	7.1
1219	1.1	0.9	0.7	0.7	1.1	1.9	3.8	6.5
1371	1.5	1.3	0.9	0.9	1.2	1.7	3.4	6.0
1524	1.8	1.6	1.3	1.1	1.3	1.6	3.1	5.7

Moisture Tension (kPa)

Depth (mm)	25 Feb	12 Mar	19 Mar	22 Mar	26 Mar	29 Mar	3 Apr	10 Apr	17 Apr
152	--	--	0	0	0	0	0	0	1.0
305	--	2.0	6.0	5.0	8.0	9.0	10.0	7.0	9.0
610	--	0.5	2.0	2.0	3.0	3.0	4.0	2.5	4.0
914	1.0	0	2.0	1.0	1.0	2.0	1.5	0	2.0

Table A10. Data from falling-weight deflectometer tests, Hyannis sand test section.

Resilient Displacement at Two Load Levels

25 February 1980 (Day 56)

Drop Height (mm):	40	219
Pressure (kPa):	273	550
Radius (mm)	Displacement	(μm)
0	99	237
200	57	153
400	35	94
800	18	50
1500	11	25

12 March 1980 (Day 72)

Drop Height (mm):	50	200
Pressure (kPa):	240	560
Radius (mm)	Displacement	(μm)
0	76	669
300	67	373
525	50	203
750	51	114
1050	38	69

19 March 1980 (Day 79)

Drop Height (mm):	100	200
Pressure (kPa):	397	552
Radius (mm)	Displacement	(μm)
0	566	842
300	273	376
525	148	216
750	91	131
1050	56	78

22 March 1980 (Day 82)

Drop Height (mm):	50	200
Pressure (kPa):	196	516
Radius (mm)	Displacement	(μm)
0	194	994
300	176	646
525	122	414
750	109	271
1050	75	142

26 March 1980 (Day 86)

Drop Height (mm):	50	200
Pressure (kPa):	244	487
Radius (mm)	Displacement	(μm)
0	439	1004
300	249	556
525	162	343
750	104	226
1050	54	115

29 March 1980 (Day 89)

Drop Height (mm):	50	200
Pressure (kPa):	255	499
Radius (mm)	Displacement	(μm)
0	491	1061
300	315	658
525	186	395
750	110	232
1050	58	117

3 April 1980 (Day 94)

Drop Height (mm)	50	200
Pressure (kPa);	248	466
Radius (mm)	Displacement	(μm)
0	536	1164
300	336	714
525	182	390
750	109	230
1050	58	114

10 April 1980 (Day 101)

Drop Height (mm):	50	200
Pressure (kPa):	226	475
Radius (mm)	Displacement	(μm)
0	579	1183
300	344	692
525	205	429
750	127	265
1050	69	138

17 April 1980 (Day 108)

Drop Height (mm):	50	200
Pressure (kPa):	221	439
Radius (mm)	Displacement	(μm)
0	562	1139
300	332	705
525	191	407
750	111	230
1050	64	123

Pavement and Subgrade Temperature (°C)

Depth (mm)	25 Feb	12 Mar	19 Mar	26 Mar	29 Mar	03 Apr	10 Apr	17 Apr
Surface	7.9	6.4	11.7	11.4	11.8	24.4	13.3	28.6
51	6.1	4.8	12.1	10.1	10.8	19.9	12.5	26.7
152	--	--	2.7	5.2	8.4	--	--	16.8
305	0.0	-0.3	1.8	2.2	5.1	5.2	7.9	9.9
457	0.3	-0.4	0.1	0.4	2.6	1.9	6.2	7.4
610	0.1	-0.4	-0.1	-0.1	0.2	1.4	5.1	7.4
762	0.3	-0.4	0.0	0.1	0.1	1.0	4.3	7.3
914	0.6	0.1	0.3	0.3	0.3	0.7	3.7	6.7
1067	0.9	--	0.6	0.4	0.6	0.7	3.3	5.8
1219	1.3	--	0.9	0.7	0.8	0.7	2.9	5.5
1371	1.6	--	1.1	1.0	1.1	0.8	2.7	5.1
1524	2.1	--	1.4	1.2	1.3	1.0	2.5	4.6

Moisture Tension

No data

Table A11. Data from falling-weight deflectometer tests, dense-graded stone test section.

Resilient Displacement at Two Load Levels

25 February 1980 (Day 56)

Drop Height (mm):	34	200
Pressure (kPa):	278	569
Radius (mm)	Displacement	(μm)
0	122	232
200	76	151
400	31	68
800	8	24
1500	7	16

12 March 1980 (Day 72)

Drop Height (mm):	50	200
Pressure (kPa):	240	525
Radius (mm)	Displacement	(μm)
0	212	731
300	158	451
525	96	255
750	63	136
1050	35	64

19 March 1980 (Day 79)

Drop Height (mm):	100	200
Pressure (kPa):	369	508
Radius (mm)	Displacement	(μm)
0	557	787
300	329	482
525	187	268
750	108	154
1050	51	72

22 March 1980 (Day 82)

Drop Height (mm):	50	200
Pressure (kPa):	201	499
Radius (mm)	Displacement	(μm)
0	123	658
300	153	487
525	127	325
750	96	203
1050	60	109

26 March 1980 (Day 86)

Drop Height (mm):	50	200
Pressure (kPa):	232	465
Radius (mm)	Displacement	(μm)
0	324	675
300	215	440
525	129	258
750	79	163
1050	41	83

29 March 1980 (Day 89)

Drop Height (mm):	50	200
Pressure (kPa):	255	470
Radius (mm)	Displacement	(μm)
0	338	646
300	237	461
525	139	263
750	77	159
1050	41	84

3 April 1980 (Day 94)

Drop Height (mm):	50	200
Pressure (kPa):	259	484
Radius (mm)	Displacement	(μm)
0	413	774
300	254	461
525	127	246
750	68	133
1050	40	75

19 April 1980 (Day 101)

Drop Height (mm):	50	200
Pressure (kPa):	241	491
Radius (mm)	Displacement	(μm)
0	362	713
300	233	472
525	141	283
750	80	162
1050	43	84

17 April 1980 (Day 108)

Drop Height (mm):	50	200
Pressure (kPa):	239	451
Radius (mm)	Displacement	(μm)
0	411	748
300	260	467
525	136	253
750	67	137
1050	39	76

Pavement and Subgrade Temperature (°C)

Depth (mm)	25 Feb	12 Mar	19 Mar	26 Mar	29 Mar	03 Apr	10 Apr	17 Apr
Surface	12.7	13.8	21.9	11.6	11.3	31.7	13.6	26.7
51	9.9	11.7	19.7	11.0	11.6	26.6	13.2	25.2
152	--	--	--	--	--	--	--	--
305	-0.2	-0.2	1.5	3.4	7.1	5.4	8.1	7.6
457	-0.1	-0.1	0.1	2.4	5.8	4.0	6.8	7.4
610	-0.1	-0.2	-0.1	1.8	4.6	3.9	5.9	7.7
762	-0.1	-0.1	-0.2	0.1	3.3	3.4	5.2	7.1
914	0.1	-0.1	0.0	0.4	2.3	2.9	4.5	6.5
1067	0.4	0.3	0.3	0.7	1.7	2.4	3.8	5.8
1219	0.8	0.7	0.8	0.9	1.5	2.0	3.3	5.0
1371	1.2	0.4	1.1	1.3	1.6	1.8	3.0	4.4
1524	1.4	0.9	1.3	1.4	1.7	1.8	2.7	4.1

Moisture Tension (kPA)

Depth (mm)	25 Feb	12 Mar	19 Mar	22 Mar	26 Mar	29 Mar	03 Apr	10 Apr	17 Apr
559	--	5.0	0.5	4.0	5.0	5.0	5.0	5.0	5.0
711	--	0	6.5	10.0	11.0	12.0	11.0	8.5	10.0

Table A12. Data from falling-weight deflectometer tests, Sibley till test section.

Resilient Displacement at Two Load Levels

25 February 1980 (Day 56)

Drop Height (mm):	36	175
Pressure (kPa):	300	575
Radius (mm)	Displacement	(µm)
0	26	69
200	18	48
400	14	32
800	8	21
1500	6	14

12 March 1980 (Day 72)

Drop Height (mm):	50	200
Pressure (kPa):	273	600
Radius (mm)	Displacement	(µm)
0	850	1700
300	369	766
525	131	286
750	34	53
1050	18	30

19 March 1980 (Day 79)

Drop Height (mm):	50	100
Pressure (kPa):	254	360
Radius (mm)	Displacement	(µm)
0	1005	1371
300	508	632
525	188	253
750	63	84
1050	25	33

22 March 1980 (Day 82)

Drop Height (mm):	50	100
Pressure (kPa):	167	330
Radius (mm)	Displacement	(µm)
0	361	1310
300	344	725
525	143	355
750	99	139
1050	48	53

26 March 1980 (Day 86)

Drop Height (mm):	50	
Pressure (kPa):	246	
Radius (mm)	Displacement	(µm)
0	759	
300	358	
525	172	
750	88	
1050	37	

29 March 1980 (Day 89)

Drop Height (mm):	50	200
Pressure (kPa):	258	505
Radius (mm)	Displacement	(µm)
0	664	1302
300	392	795
525	147	311
750	65	143
1050	37	74

3 April 1980 (Day 94)

Drop Height (mm):	50	200
Pressure (kPa):	265	516
Radius (mm)	Displacement	(µm)
0	789	1460
300	338	666
525	114	245
750	50	107
1050	34	69

10 April 1980 (Day 101)

Drop Height (mm):	50	200
Pressure (kPa):	248	504
Radius (mm)	Displacement	(µm)
0	642	1237
300	343	715
525	113	251
750	57	124
1050	32	63

17 April 1980 (Day 108)

Drop Height (mm):	50	200
Pressure (kPa):	240	455
Radius (mm)	Displacement	(µm)
0	624	1144
300	323	631
525	122	246
750	49	105
1050	33	67

Pavement and Subgrade Temperatures (°C)

Depth (mm)	25 Feb	12 Mar	22 Mar	26 Mar
Surface	3.6	17.0	4.4	14.0
50	2.8	14.6	4.5	11.0
230	-0.7	1.0	1.4	3.3
330	-0.6	0.6	1.5	3.1
410	-0.3	0.2	1.4	3.0
520	-0.3	0.1	1.0	2.8
600	-0.3	0.1	0.8	2.7
680	-0.6	0.1	0.5	2.5
830	-0.1	0.2	0.2	2.2
1090	0.9	0.2	0.5	1.6
1030	0.3	0.2	0.8	1.4

Moisture Tension (kPa)

Depth (mm)	25 Feb	12 Mar	19 Mar	22 Mar	26 Mar	29 Mar	3 Apr	10 Apr	17 Apr
152	0	0	0	0	0	0	1.0	0	6.0
305	1.0	0	0	0	0	0	0	0	0
610	0	0.5	0	0	0	0	0	0	0
914	3.0	2.5	2.0	0	0	1.0	1.5	1.0	2.0

APPENDIX B: GROUND TEMPERATURES PREVAILING DURING PLATE-LOADING TESTS

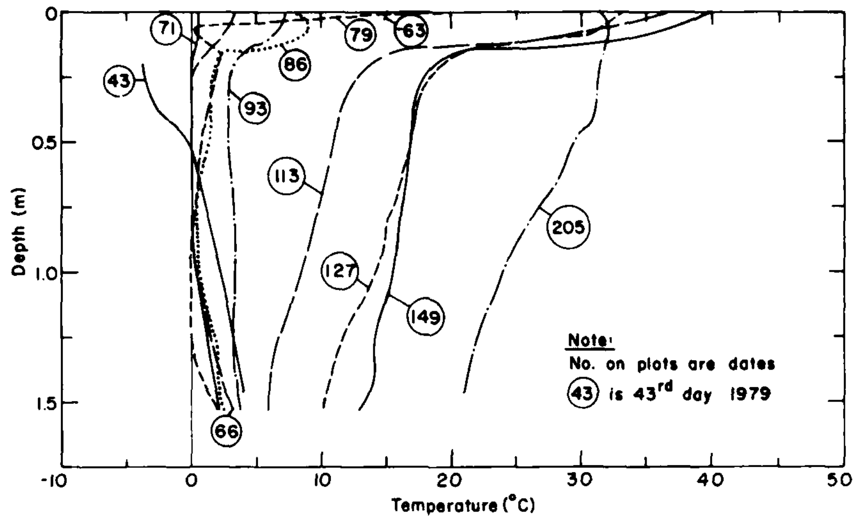


Figure B1. Ikalanian sand, 1979.

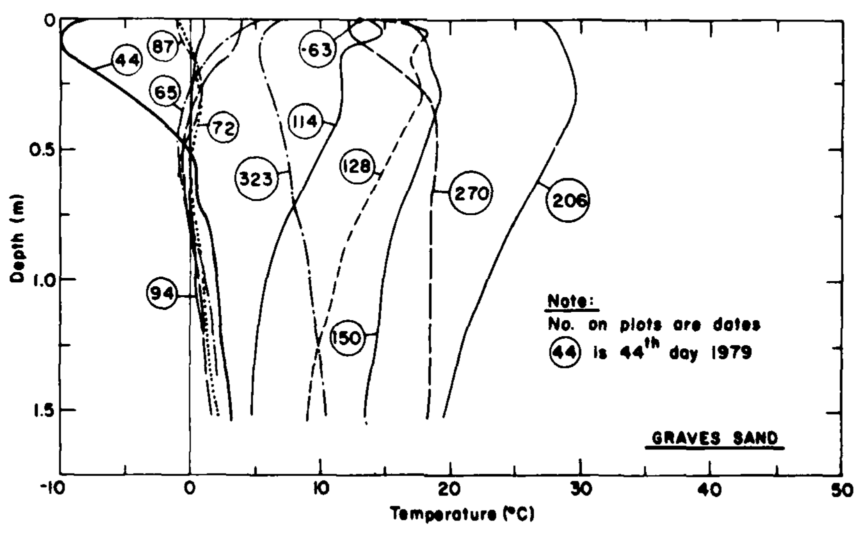


Figure B2. Graves sand, 1979.

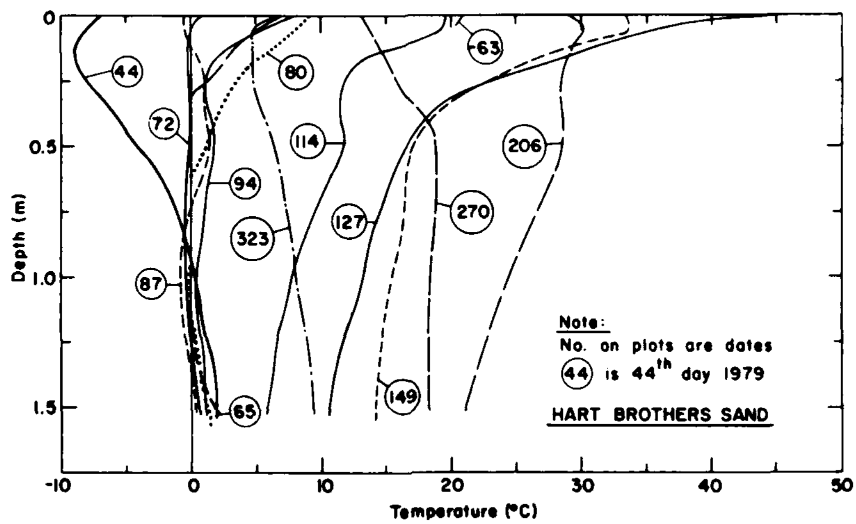


Figure B3. Hart Brothers sand, 1979.

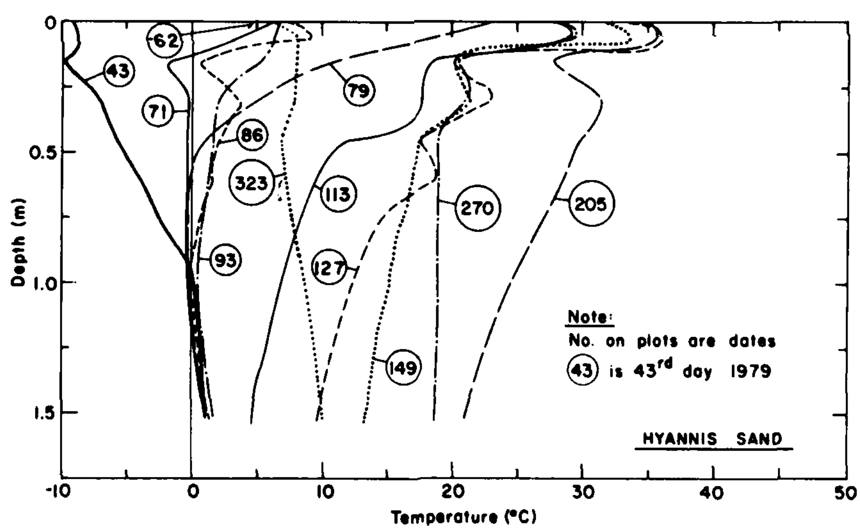


Figure B4. Hyannis sand, 1979.

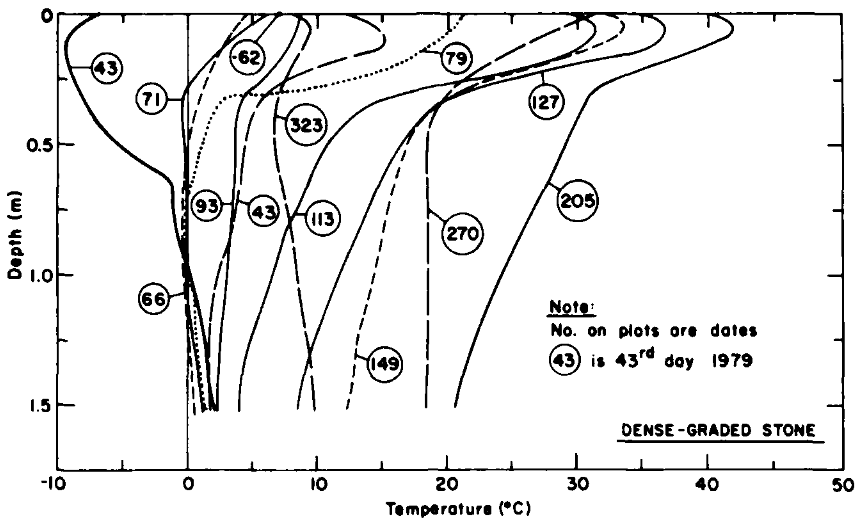


Figure B5. Dense-graded stone, 1979.

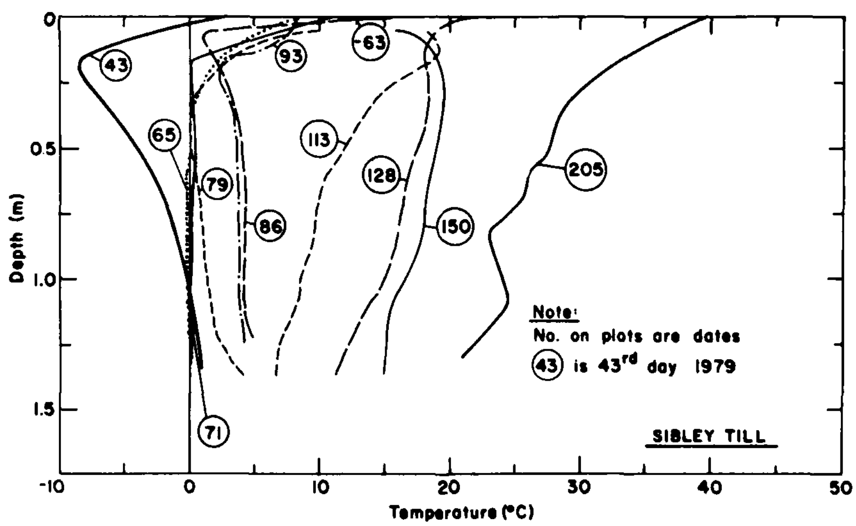


Figure B6. Sibley till, 1979.

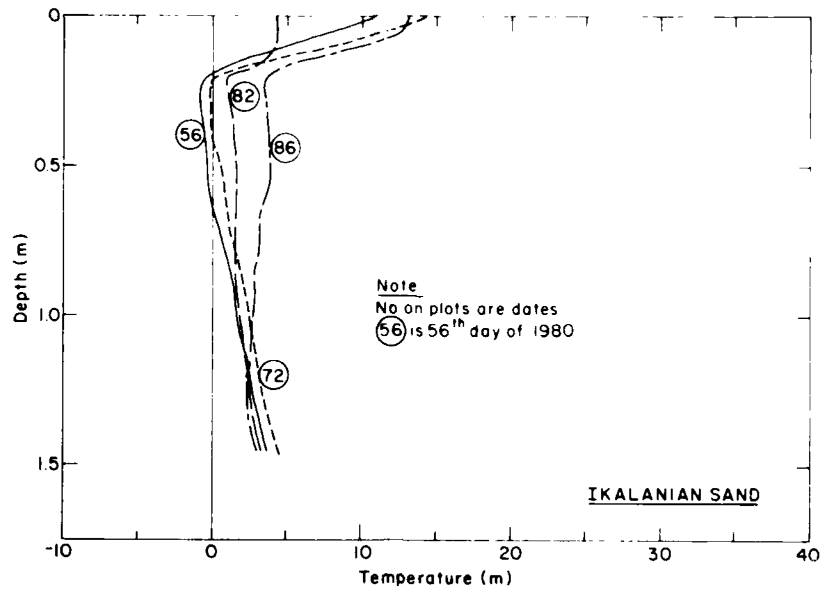


Figure B7. Ikalanian sand, 1980.

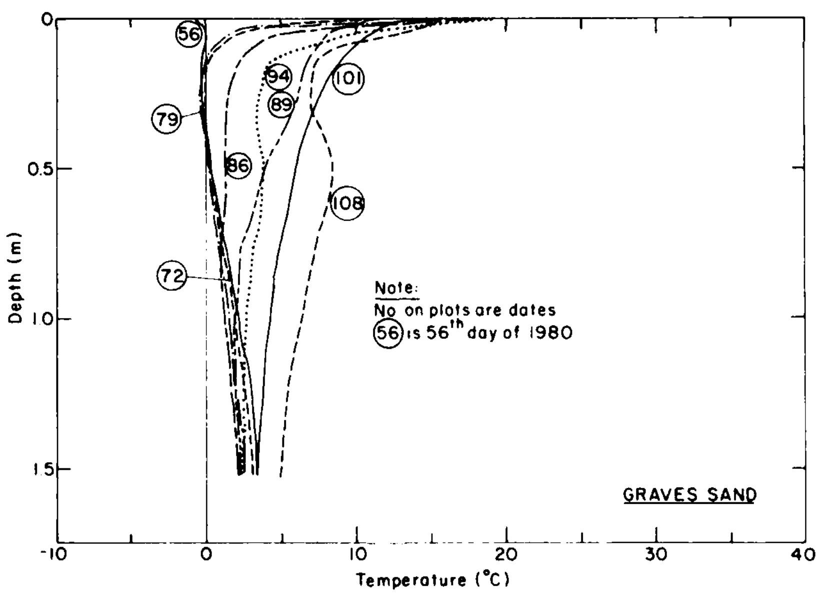


Figure B8. Graves sand, 1980.

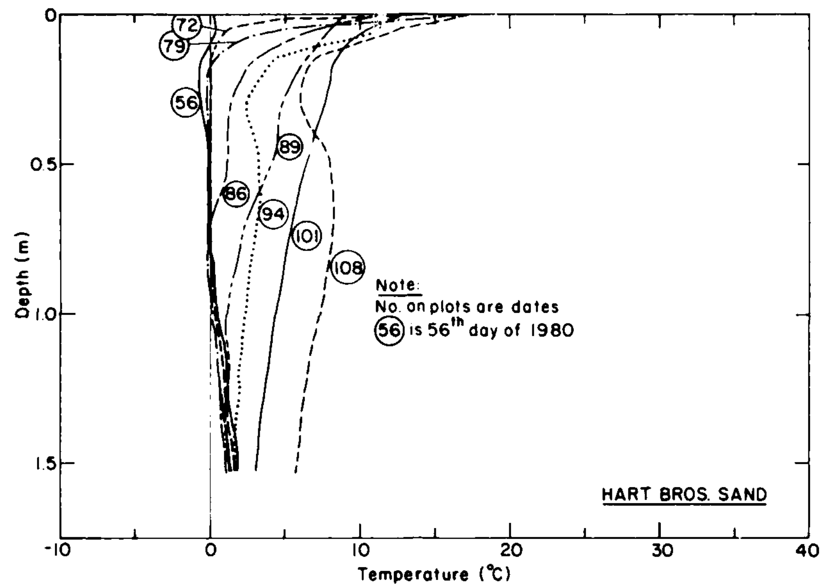


Figure B9. Hart Brothers sand, 1980.

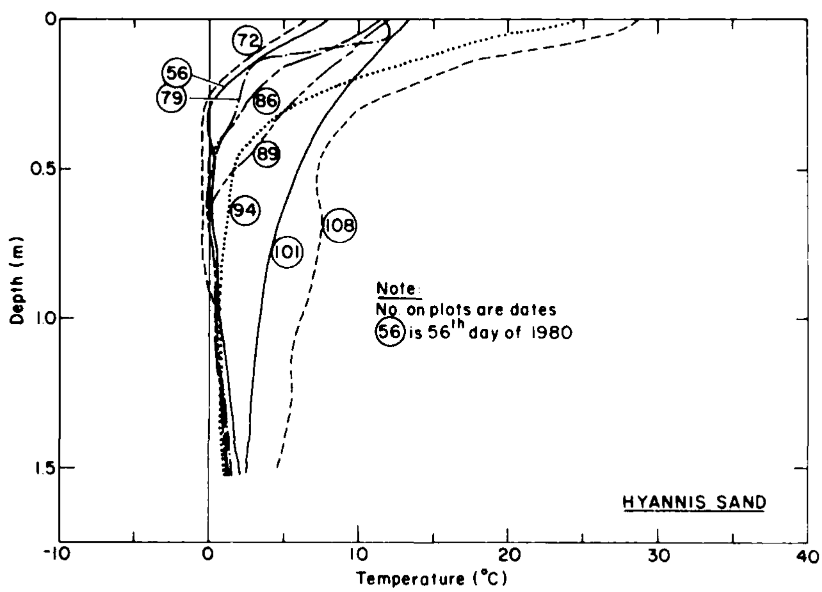


Figure B10. Hyannis sand, 1980.

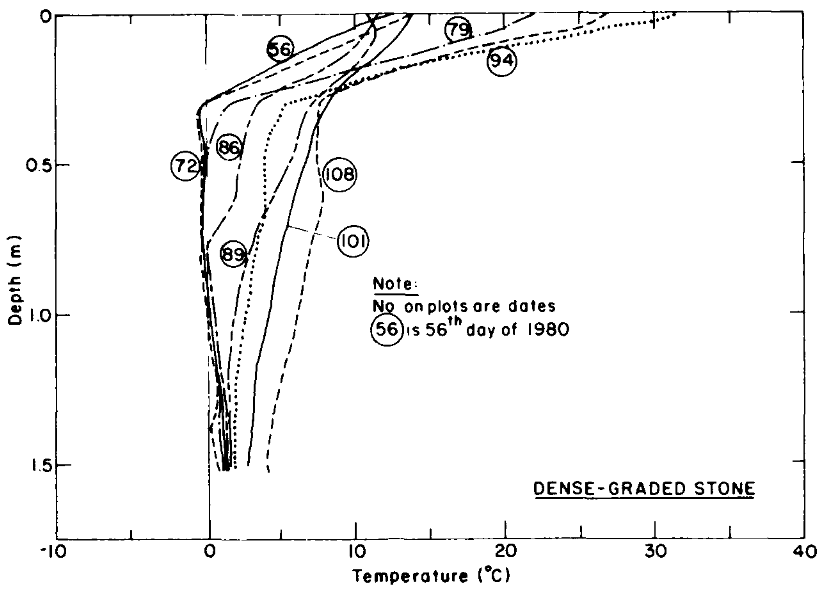


Figure B11. Dense-graded stone, 1980.

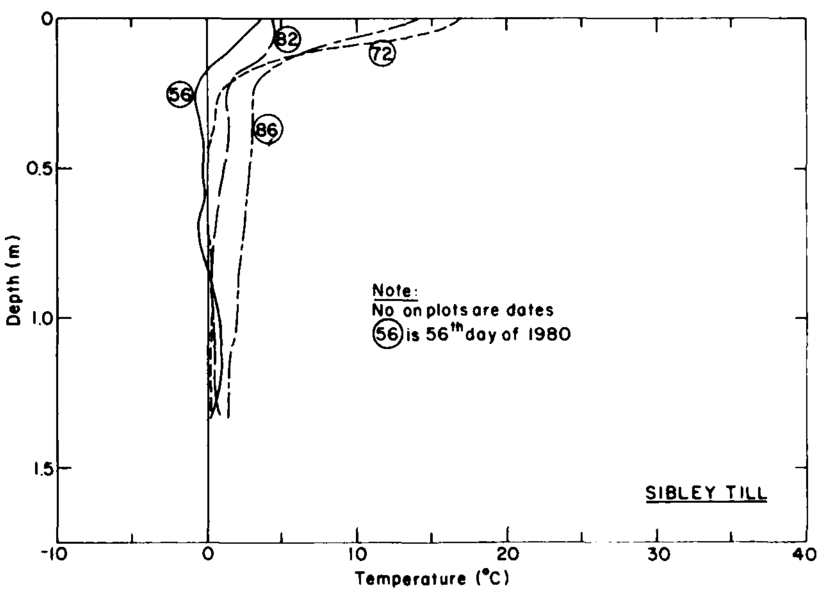
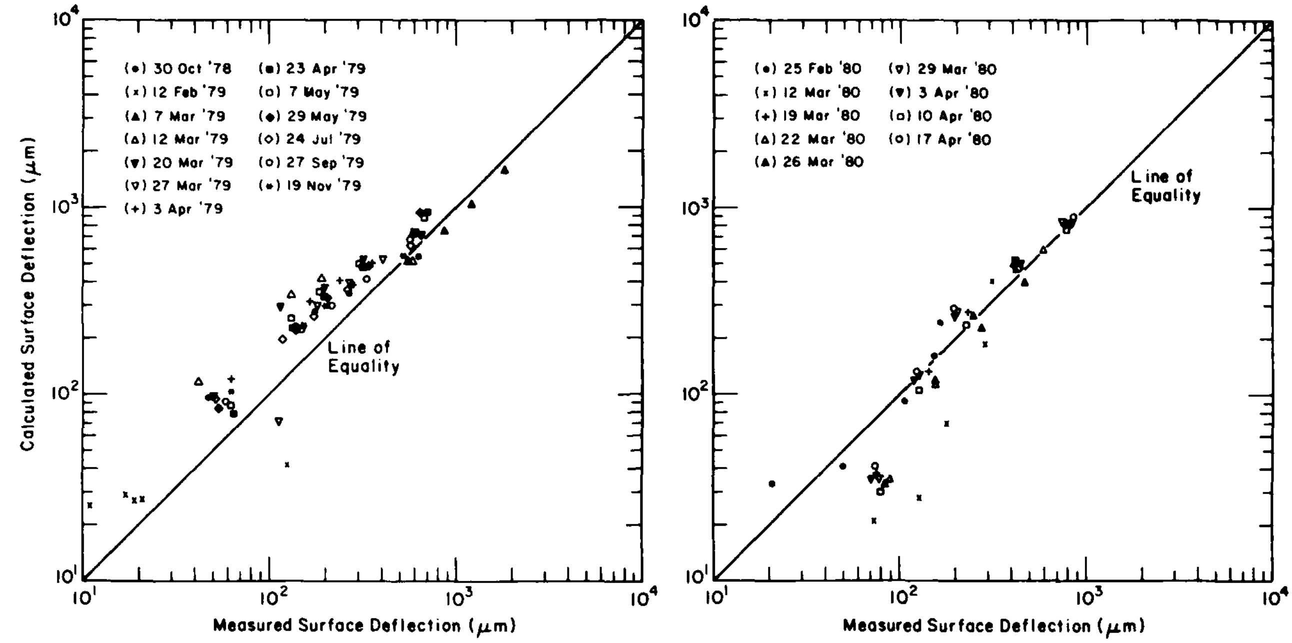


Figure B12. Sibley till, 1980.

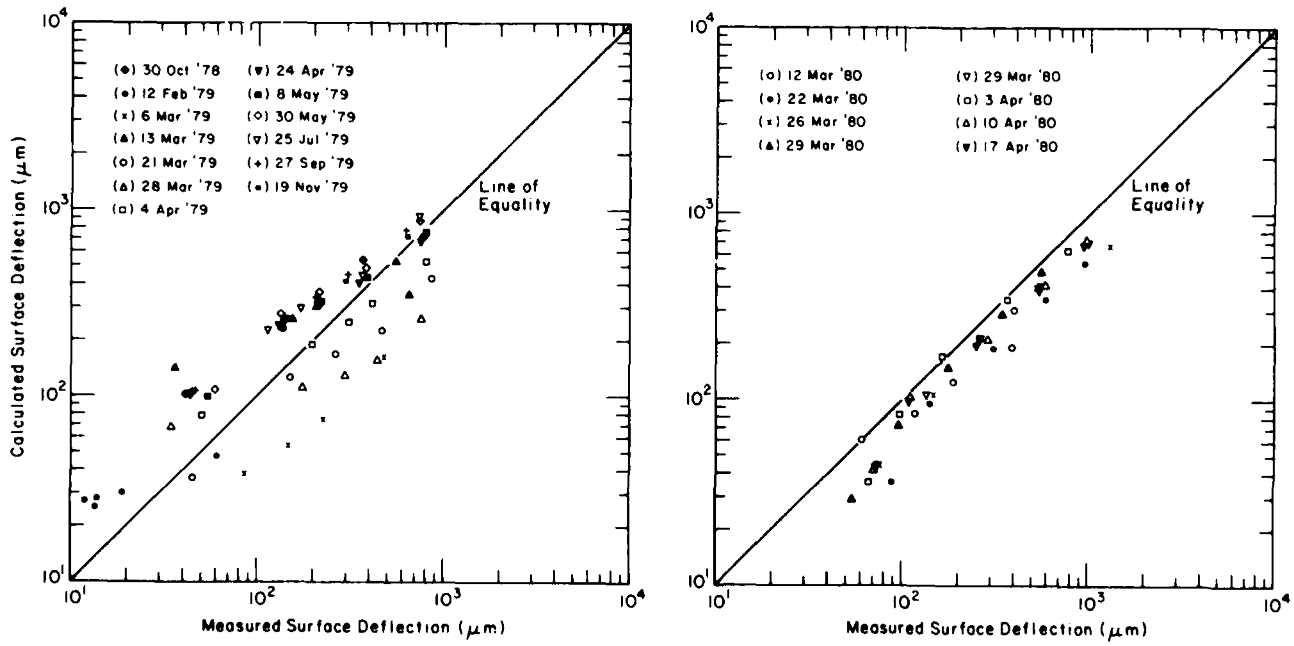
APPENDIX C: MEASURED SURFACE DEFLECTIONS COMPARED WITH DEFLECTIONS CALCULATED BY NELAPAV
(Lower of two levels of applied plate pressure)



a. 1979 RPB tests at 243-283 kPa plate pressure.

b. 1980 FWD tests at 207-275 kPa plate pressure.

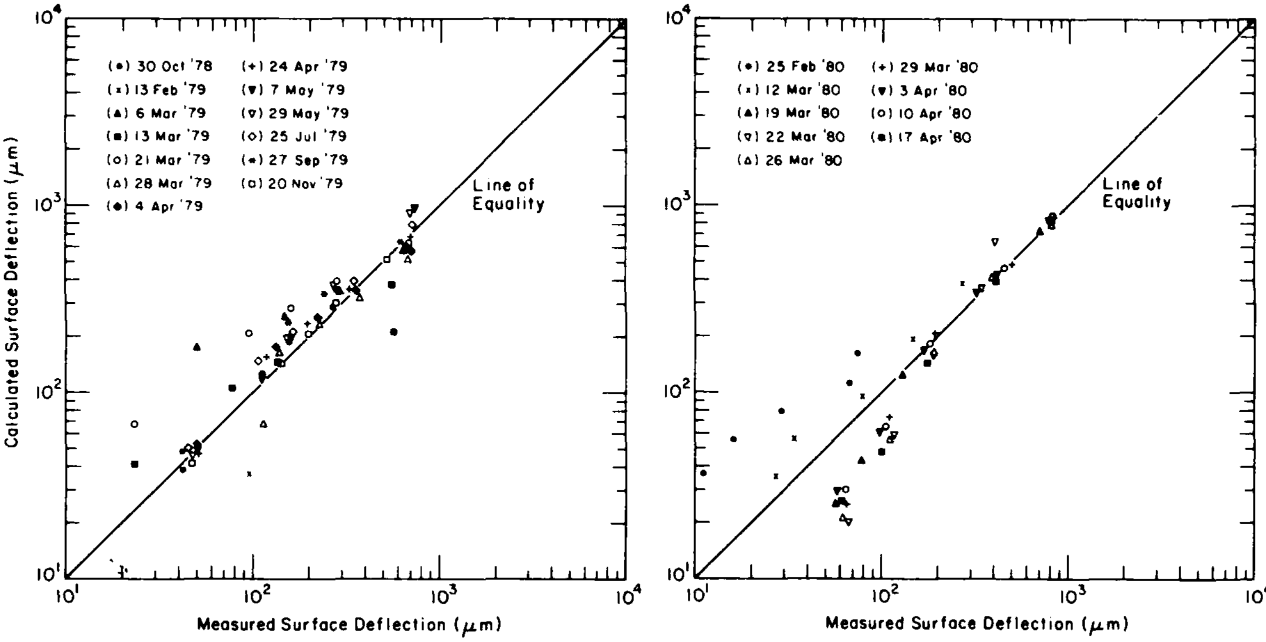
Figure C1. Measured surface deflections compared with deflections calculated by NELAPAV, Ikalanian sand test section.



a. 1979 RPB tests at 101–298 kPa plate pressure.

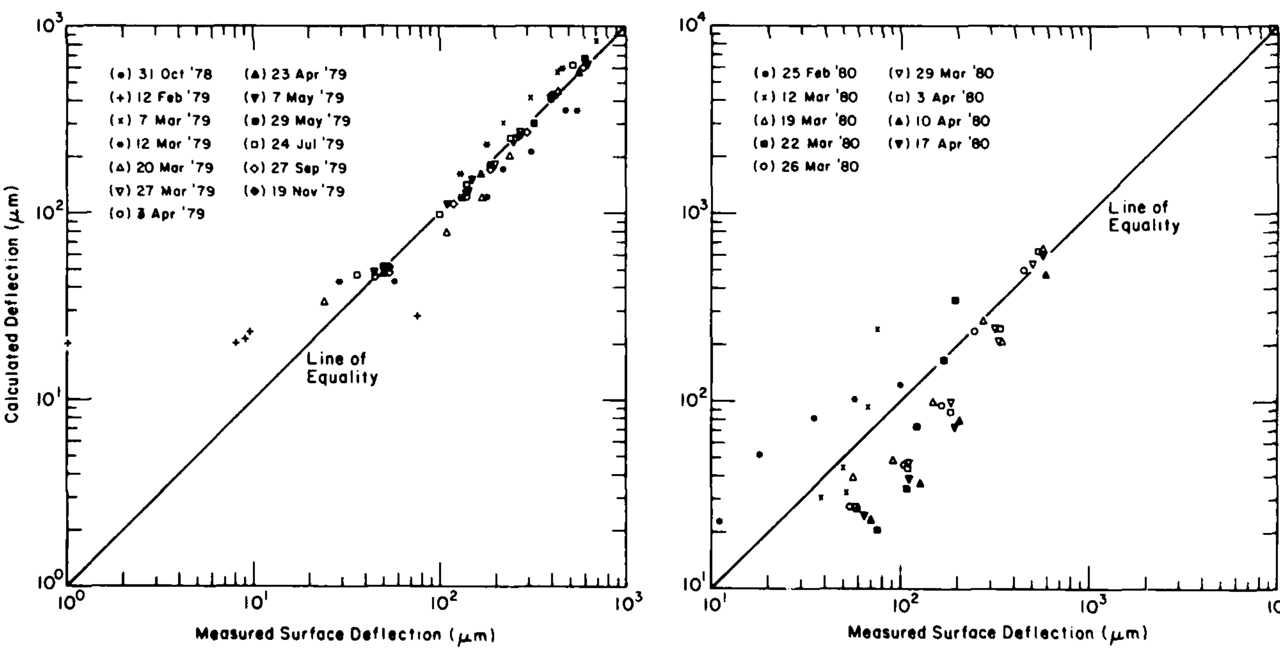
b. 1980 FWD tests at 159–250 kPa plate pressure.

Figure C2. Measured surface deflections compared with deflections calculated by NELAPAV, Graves sand test section.



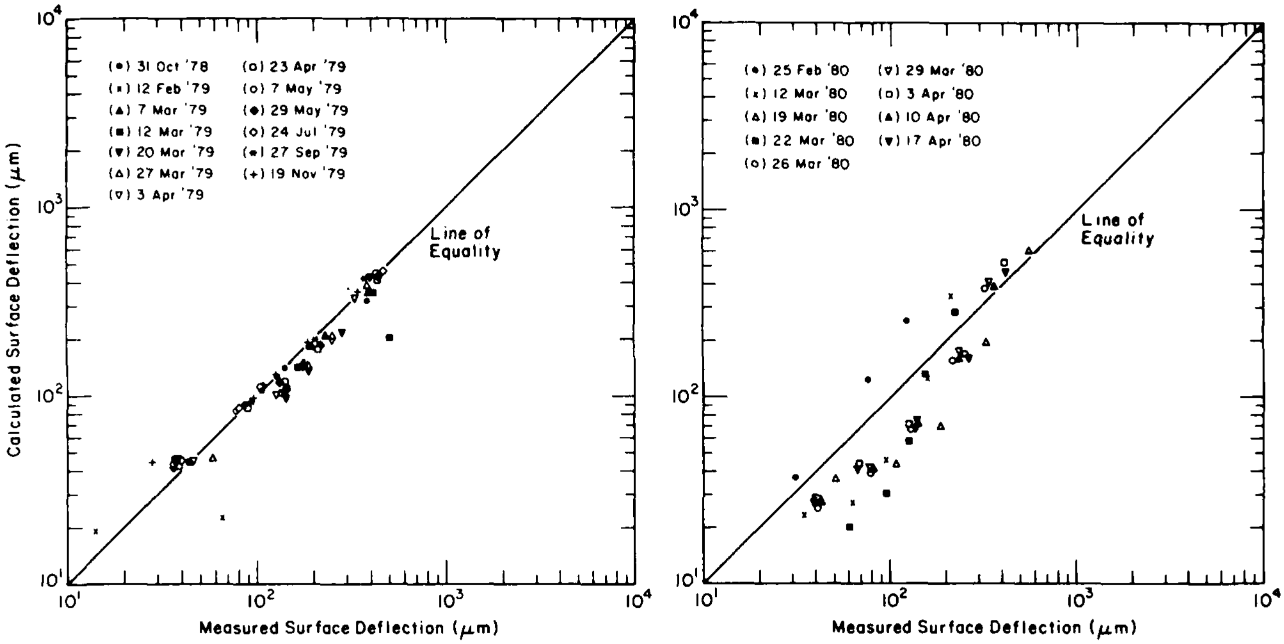
a. 1979 RPB tests at 245–285 kPa plate pressure. *b. 1980 FWD tests at 195–265 kPa plate pressure.*

Figure C3. Measured surface deflections compared with deflections calculated by NELAPAV, Hart Brothers sand test section.



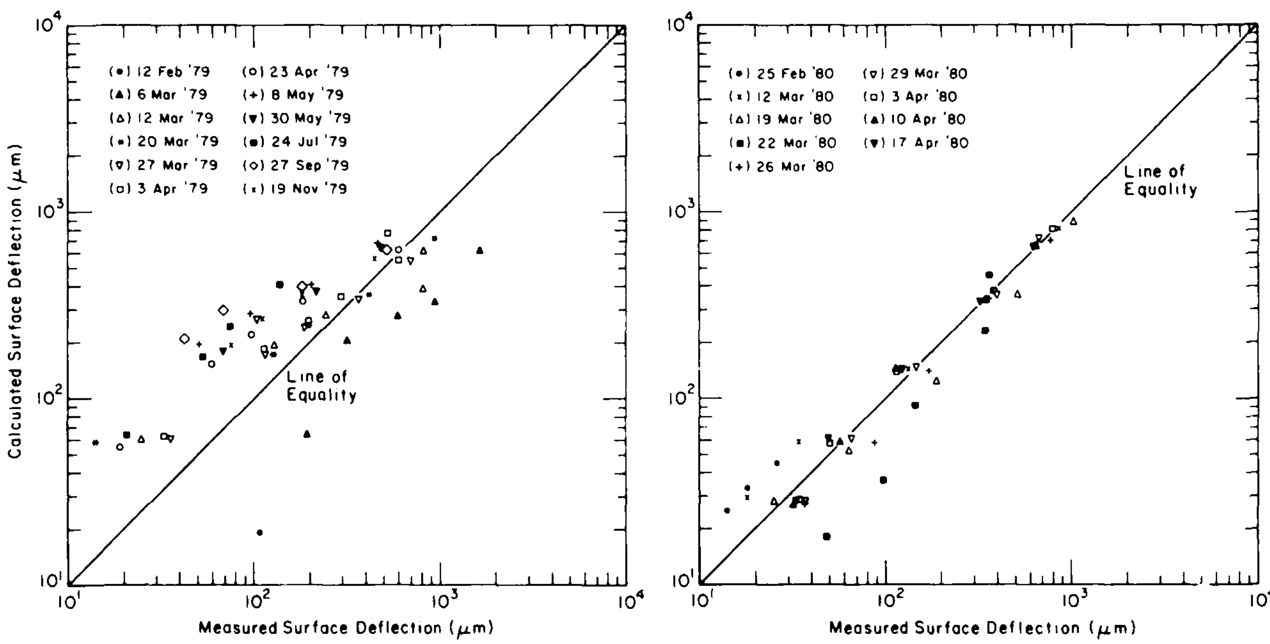
a. 1979 RPB tests at 215–283 kPa plate pressure. *b. 1980 FWD tests at 196–397 kPa plate pressure.*

Figure C4. Measured surface deflections compared with deflections calculated by NELAPAV, Hyannis sand test section.



a. 1979 RPB tests at 249–274 kPa plate pressure. *b. 1980 FWD tests at 201–369 kPa plate pressure.*

Figure C5. Measured surface deflections compared with deflections calculated by NELAPAV, dense-graded stone test section.



a. 1979 RPB tests at 246–281 kPa plate pressure. *b. 1980 FWD tests at 167–300 kPa plate pressure.*

Figure C6. Measured surface deflections compared with deflections calculated by NELAPAV, Sibley till test section.

APPENDIX D: RESILIENT MODULI AND SUPPORTING DATA CALCULATED BY NELAPAV

Table D1a. Resilient moduli and supporting data calculated by NELAPAV for Ikalanian test section, 1979.

30 October 1978 (Day 63)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		258.7		517.4				
0.050	Asphalt Concrete	3412.0	--	3412.0	--	15.2°	2.320	.45
0.250	I.S. (thawed)	78.0	-92.83	105.7	-171.60	10.0 kPa	1.656	.35
0.350	I.S. (thawed)	51.3	-39.33	58.1	- 50.63	10.0 kPa	1.656	.35
0.874	I.S. (thawed)	33.1	-60.39	34.8	- 66.98	5.0 kPa	1.590	.40
1.524	Subgrade	177.0	-66.88	180.8	- 68.89	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

12 February 1979 (Day 43)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		249.0		573.0				
0.050	Asphalt Concrete	15705.0	--	15705.0	--	-10°	2.320	.30
0.250	I.S. (frozen)	8398.1	τ_{oct}=52.18	6090.4	τ_{oct}=120.99	-3.5°	1.444	.35
0.350	I.S. (frozen)	7141.5	τ_{oct}=18.77	5296.1	τ_{oct}=410.62	-2.4°	1.504	.35
0.874	I.S. (thawed)	38.0	-52.39	39.1	- 55.55	7.0 kPa	1.609	.40
1.524	Subgrade	172.3	-64.37	175.8	- 66.26	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

7 March 1979 (Day 66)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		264		532				
0.050	Asphalt Concrete	2634.0	--	2634.0	--	3°	2.320	.40
0.250	I.S. (thawed)	12.2	-107.90	17.3	-219.60	0 kPa	1.444	.45
0.350	I.S. (thawed)	14.6	- 59.63	18.4	- 95.52	0 kPa	1.504	.45
0.874	I.S. (thawed)	25.2	- 61.35	27.7	- 72.61	0 kPa	1.576	.45
1.524	Subgrade	173.1	- 64.76	179.3	- 68.09	--	1.055	.35
-	Subgrade	200.0	--	--	--	--	1.055	.35

12 March 1979 (Day 71)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		281		545				
0.050	Asphalt Concrete	10000.0	--	10000.0	--	0.5°	2.320	.35
0.250	I.S. (thawed)	33.8	- 90.07	46.4	-171.10	0 kPa	1.590	.45
0.350	I.S. (thawed)	28.2	- 53.46	34.0	- 78.30	2 kPa	1.590	.45
0.874	I.S. (thawed)	33.4	- 61.72	35.5	- 69.57	5 kPa	1.590	.40
1.524	Subgrade	176.2	- 66.40	180.2	- 68.56	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

20 March 1979 (Day 79)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		256		535				
0.050	Asphalt Concrete	5174.0	--	5174.0	--	10°	2.320	.40
0.250	I.S. (thawed)	42.2	- 85.95	59.1	-171.10	7 kPa	1.590	.40
0.350	I.S. (thawed)	29.4	- 47.50	35.5	- 69.52	5 kPa	1.590	.40
0.874	I.S. (thawed)	33.1	- 60.31	35.2	- 68.59	5 kPa	1.590	.40
1.524	Subgrade	175.7	- 66.18	180.0	- 68.43	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

27 March 1979 (Day 86)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		247		548				
0.050	Asphalt Concrete	5600.0	--	5600.0	--	8°	2.320	.40
0.250	I.S. (thawed)	38.5	- 82.43	55.7	-174.60	5 kPa	1.590	.40
0.350	I.S. (thawed)	29.2	- 46.86	35.8	- 70.96	5 kPa	1.590	.40
0.874	I.S. (thawed)	33.0	- 60.07	35.4	- 69.09	5 kPa	1.590	.40
1.524	Subgrade	175.6	- 66.10	180.2	- 68.54	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

3 April 1979 (Day 93)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		261		547				
0.050	Asphalt Concrete	6423.0	--	6423.0	--	7°	2.320	.40
0.250	I.S. (thawed)	41.4	- 82.79	57.4	-160.80	7 kPa	1.590	.40
0.350	I.S. (thawed)	29.4	- 47.46	35.2	- 68.38	5 kPa	1.590	.40
0.874	I.S. (thawed)	33.1	- 60.45	35.2	- 68.37	5 kPa	1.590	.40
1.524	Subgrade	175.8	- 66.22	180.2	- 68.42	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

23 April 1979 (Day 113)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		253		539				
0.050	Asphalt Concrete	450.0	--	450.0	--	35°	2.320	.40
0.250	I.S. (thawed)	49.3	-136.60	69.9	-277.10	5 kPa	1.590	.40
0.350	I.S. (thawed)	32.6	- 50.55	39.7	- 75.72	7 kPa	1.590	.40
0.874	I.S. (thawed)	33.1	- 60.45	35.4	- 69.37	5 kPa	1.590	.40
1.524	Subgrade	175.6	- 66.10	179.9	- 68.39	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

7 May 1979 (Day 127)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		264		547				
0.050	Asphalt Concrete	556.3	--	556.3	--	33°	2.320	.40
0.250	I.S. (thawed)	54.0	-132.30	75.3	-260.80	8 kPa	1.590	.40
0.350	I.S. (thawed)	30.5	- 51.11	37.0	- 75.64	5 kPa	1.590	.40
0.874	I.S. (thawed)	33.2	- 60.74	35.5	- 69.50	5 kPa	1.590	.40
1.524	Subgrade	175.8	- 66.19	180.0	- 68.46	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

29 May 1979 (Day 149)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		261		552				
0.050	Asphalt Concrete	295.1	--	295.1	--	38°	2.320	.40
0.250	I.S. (thawed)	55.8	-141.50	78.8	-285.90	8 kPa	1.590	.40
0.350	I.S. (thawed)	30.7	- 51.76	37.6	- 78.14	5 kPa	1.590	.40
0.874	I.S. (thawed)	33.2	- 60.82	35.6	- 70.06	5 kPa	1.590	.40
1.524	Subgrade	175.7	- 66.17	180.1	- 68.51	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

24 July 1979 (Day 206)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		271		552				
0.050	Asphalt Concrete	700.0	--	700.0	--	32°	2.320	.40
0.250	I.S. (thawed)	91.6	-128.30	126.1	-246.30	10 kPa	1.656	.35
0.350	I.S. (thawed)	54.6	- 41.51	63.0	- 55.42	11 kPa	1.656	.35
0.874	I.S. (thawed)	33.4	- 61.47	35.5	- 69.53	5 kPa	1.590	.40
1.524	Subgrade	174.8	- 66.48	179.3	- 68.71	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

27 September 1979 (Day 270)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		274		584				
0.050	Asphalt Concrete	978.0	--	978.0	--	28°	2.320	.40
0.250	I.S. (thawed)	84.0	-107.70	118.0	-215.20	10 kPa	1.656	.40
0.350	I.S. (thawed)	36.0	- 46.88	43.4	- 68.55	7 kPa	1.609	.40
0.874	I.S. (thawed)	41.1	- 61.82	44.1	- 71.23	7 kPa	1.609	.40
1.524	Subgrade	175.6	- 66.47	179.7	- 68.90	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

19 November 1979 (Day 323)

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
Plate Pressure (kPa):		281		591				
0.050	Asphalt Concrete	5600.0	--	5600.0	--	8°	2.320	.40
0.250	I.S. (thawed)	773.0	- 90.78	107.2	-176.60	10 kPa	1.656	.35
0.350	I.S. (thawed)	51.7	- 40.01	59.4	- 53.09	10 kPa	1.656	.35
0.874	I.S. (thawed)	33.4	- 61.35	35.5	- 69.51	5 kPa	1.590	.40
1.524	Subgrade	175.7	- 66.54	179.7	- 68.92	--	1.055	.35
-	Subgrade	200.0	--	200.0	--	--	1.055	.35

Notes:
(1) Moduli, stresses, and strains calculated by NELAPAV.
(2) M_r = resilient modulus, J_1 = first stress invariant or bulk stress, ϕ = moisture tension, γ_d = dry unit weight, μ_r = resilient Poisson's ratio
(3) M_r and J_1 are calculated at r=0 and center of respective layer
(4) I.S. refers to Ikalanian sand (never frozen except as noted).
(5) τ_{oct} = octahedral shear stress (kPa)
(6) Negative normal stresses and strains are compressive.

Tangential Strain ϵ_t (r = 0, z = .05) and Vertical Strain ϵ_v (r = 0, z = 1.5)

	30 Oct	12 Feb	7 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	7 May	29 May	24 Jul	27 Sep	19 Nov
ϵ_t (low pressure):	3.154×10^{-4}	-1.307×10^{-7}	8.620×10^{-4}	2.930×10^{-4}	3.603×10^{-4}	3.421×10^{-4}	3.274×10^{-4}	7.157×10^{-4}	6.796×10^{-4}	6.357×10^{-4}	3.833×10^{-4}	4.309×10^{-4}	2.823×10^{-4}
(high pressure)	5.265×10^{-4}	-2.967×10^{-6}	1.545×10^{-3}	5.124×10^{-4}	6.537×10^{-4}	6.572×10^{-4}	6.013×10^{-4}	1.064×10^{-3}	1.007×10^{-3}	8.728×10^{-4}	5.334×10^{-4}	6.487×10^{-4}	5.014×10^{-4}
ϵ_v (low pressure)	-1.921×10^{-4}	-1.743×10^{-4}	-1.700×10^{-4}	-2.110×10^{-4}	-2.021×10^{-4}	-2.015×10^{-4}	-2.031×10^{-4}	-2.038×10^{-4}	-2.061×10^{-4}	-2.065×10^{-4}	-1.326×10^{-4}	-1.352×10^{-4}	-1.325×10^{-4}
(high pressure)	-2.405×10^{-4}	-1.095×10^{-4}	-2.413×10^{-4}	-2.720×10^{-4}	-2.631×10^{-4}	-2.673×10^{-4}	-2.652×10^{-4}	-2.700×10^{-4}	-2.709×10^{-4}	-2.747×10^{-4}	-1.551×10^{-4}	-1.571×10^{-4}	-1.508×10^{-4}

Table D1b. Resilient moduli and supporting data calculated by NELAPAV for Ikalanian test section, 1980.

25 February 1980 (Day 56)

Plate Pressure (kPa): 275 / 583

Thickness (m)	Materials	M_r (MPa) [275]	J_1 (kPa) [275]	M_r (MPa) [583]	J_1 (kPa) [583]	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	9115.0	--	9115.0	--	9.6°	2.320	.40
0.100	I.S. (thawed)	32.7	-309.20	49.2	-711.40	0 kPa	1.504	.45
0.500	I.S. (frozen)	1956.7	τ_{oct}=20.44	1432.9	τ_{oct}= 46.19	-.5°	1.444	.35
0.874	I.S.	36.6	- 54.24	38.2	- 59.02	9 kPa	1.590	.35
1.524	Subgrade	171.1	- 64.39	173.1	- 66.52	--	1.055	.35
∞	Subgrade	200.0	--	--	--	--	1.055	.35

12 March 1980 (Day 72)

Plate Pressure (kPa): 237

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	6860.0	--	13°	2.320	.40
0.325	I.S. (thawed)	42.0	-210.60	2 kPa	1.590	.45
0.325	I.S. (frozen)	2326.2	τ_{oct}=13.00	-.5°	1.504	.35
0.874	I.S.	42.8	- 57.87	9 kPa	1.609	.40
1.524	Subgrade	173.2	- 65.64	--	1.055	.35
∞	Subgrade	200.0	--	--	1.055	.35

12 March 1980 (Day 72)

Plate Pressure (kPa): 594

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	6860.0	--	13°	2.320	.40
0.325	I.S. (thawed)	43.3	-128.60	2 kPa	1.590	.45
0.325	I.S. (thawed)	16.9	- 70.34	2 kPa	1.504	.45
0.874	I.S.	47.1	- 70.19	9 kPa	1.609	.40
1.524	Subgrade	177.4	- 68.19	--	1.055	.35
∞	Subgrade	200.0	--	--	1.055	.35

19 March 1980 (Day 79)

Plate Pressure (kPa): 273 / 363

Thickness (m)	Materials	M_r (MPa) [273]	J_1 (kPa) [273]	M_r (MPa) [363]	J_1 (kPa) [363]	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	9154.0	--	9154.0	--	10°	2.320	.45
0.325	I.S. (thawed)	31.2	- 75.22	35.4	- 97.26	0 kPa	1.590	.45
0.325	I.S. (thawed)	27.2	- 49.25	28.9	- 55.95	2 kPa	1.590	.45
0.824	I.S.	29.2	- 61.61	29.8	- 64.29	4 kPa	1.576	.40
1.524	Subgrade	171.6	- 66.08	173.0	- 66.82	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

22 March 1980 (Day 82)

Plate Pressure (kPa): 207 / 319

Thickness (m)	Materials	M_r (MPa) [207]	J_1 (kPa) [207]	M_r (MPa) [319]	J_1 (kPa) [319]	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	13440.0	--	13440.0	--	4.4°	2.320	.40
0.325	I.S. (thawed)	26.3	- 53.21	31.5	- 77.00	0 kPa	1.590	.45
0.325	I.S. (thawed)	25.0	- 41.88	27.1	- 49.47	2 kPa	1.590	.45
0.824	I.S.	25.3	- 60.42	26.1	- 64.27	0 kPa	1.576	.45
1.524	Subgrade	171.1	- 65.54	173.7	- 66.48	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

26 March 1980 (Day 86)

Plate Pressure (kPa): 253 / 358

Thickness (m)	Materials	M_r (MPa) [253]	J_1 (kPa) [253]	M_r (MPa) [358]	J_1 (kPa) [358]	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	7124.0	--	7124.0	--	12.9°	2.320	.40
0.325	I.S. (thawed)	31.3	- 76.03	36.5	-103.80	0 kPa	1.590	.45
0.325	I.S. (thawed)	27.3	- 43.63	29.1	- 49.88	4 kPa	1.590	.40
0.824	I.S.	25.6	- 62.12	26.3	- 24.95	0 kPa	1.576	.45
1.524	Subgrade	175.3	- 65.92	176.9	- 66.79	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

29 March 1980 (Day 88)

Plate Pressure (kPa): 253 / 350

Thickness (m)	Materials	M_r (MPa) [253]	J_1 (kPa) [253]	M_r (MPa) [350]	J_1 (kPa) [350]	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	[illegible]	[illegible]	[illegible]	[illegible]	12°	2.320	.45
0.325	I.S. (thawed)	[illegible]	[illegible]	35.5	[illegible]	0 kPa	1.590	.45
0.325	I.S. (thawed)	[illegible]	[illegible]	26.4	- 50.15	4 kPa	1.590	.40
0.824	I.S.	25.6	[illegible]	26.1	[illegible]	0 kPa	1.576	.45
1.524	Subgrade	[illegible]	- 65.91	[illegible]	[illegible]	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

3 April 1980 (Day 94)

Plate Pressure (kPa): 248 / 355

Thickness (m)	Materials	M_r (MPa) [248]	J_1 (kPa) [248]	M_r (MPa) [355]	J_1 (kPa) [355]	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	6909.0	--	6090.0	--	18°	2.320	.50
0.325	I.S. (thawed)	35.1	- 72.73	40.9	- 99.65	2 kPa	1.590	.45
0.325	I.S. (thawed)	24.7	- 43.48	26.4	- 49.87	4 kPa	1.590	.40
0.824	I.S.	25.6	- 61.80	26.3	- 35.25	0 kPa	1.576	.45
1.524	Subgrade	171.2	- 65.88	172.8	- 66.72	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

10 April 1980 (Day 101)

Plate Pressure (kPa): 230 / 332

Thickness (m)	Materials	M_r (MPa) [230]	J_1 (kPa) [230]	M_r (MPa) [332]	J_1 (kPa) [332]	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	6090.0	--	6090.0	--	15°	2.320	.40
0.325	I.S. (thawed)	32.7	- 72.44	38.4	- 99.88	2 kPa	1.590	.45
0.325	I.S. (thawed)	26.9	- 42.24	28.7	- 48.28	4 kPa	1.590	.40
0.824	I.S.	25.5	- 61.29	26.1	- 64.71	0 kPa	1.576	.45
1.524	Subgrade	174.9	- 65.73	176.5	- 66.57	--	1.055	.45
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

17 April 1980 (Day 108)

Plate Pressure (kPa): 270 / 370

Thickness (m)	Materials	M_r (MPa) [270]	J_1 (kPa) [270]	M_r (MPa) [370]	J_1 (kPa) [370]	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	6090.0	--	6090.0	--	17°	2.320	.50
0.325	I.S. (thawed)	31.9	- 73.65	36.6	- 97.74	4 kPa	1.590	.40
0.325	I.S. (thawed)	29.3	- 43.96	31.3	- 49.58	6 kPa	1.590	.38
0.824	I.S.	27.5	- 62.65	28.2	- 60.01	2 kPa	1.576	.45
1.524	Subgrade	171.6	- 66.06	173.1	- 66.88	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

* Notes:

(1) Moduli, stresses, and strains calculated by NELAPAV

(2) M_r = resilient modulus, J_1 = first stress invariant or bulk stress, ϕ = moisture tension, γ_d = dry unit weight, μ_r = resilient Poisson's ratio

(3) M_r and J_1 are calculated at r=0 and center of respective layer

(4) I.S. refers to Ikalanian sand (never frozen except as noted).

(5) τ_{oct} = octahedral shear stress (kPa)

(6) Negative normal stresses and strains are compressive.

Tangential Strain ϵ_t (r = 0, z = .05) and Vertical Strain ϵ_v (r = 0, z = 1.524)

	25 Feb	12 Mar	19 Mar	22 Mar	26 Mar	29 Mar	3 Apr	10 Apr	17 Apr
ϵ_t (low pressure):	1.663×10^{-4}	2.422×10^{-4}	2.843×10^{-4}	1.792×10^{-4}	3.189×10^{-4}	3.129×10^{-4}	3.149×10^{-4}	3.167×10^{-4}	3.484×10^{-4}
(high pressure):	3.118×10^{-4}	6.476×10^{-4}	3.645×10^{-4}	2.644×10^{-4}	4.304×10^{-4}	4.142×10^{-4}	4.279×10^{-4}	4.325×10^{-4}	4.559×10^{-4}
ϵ_v (low pressure):	-1.162×10^{-4}	-1.209×10^{-4}	-1.370×10^{-4}	-1.500×10^{-4}	-1.361×10^{-4}	-1.361×10^{-4}	-1.358×10^{-4}	-1.340×10^{-4}	-1.382×10^{-4}
(high pressure):	-1.253×10^{-4}	-1.562×10^{-4}	-1.441×10^{-4}	-1.788×10^{-4}	-1.448×10^{-4}	-1.442×10^{-4}	-1.445×10^{-4}	-1.424×10^{-4}	-1.452×10^{-4}

Table D2a. Resilient moduli and supporting data calculated by NELAPAV for Graves sand test section, 1979.

30 October 1978 (Day 63)

Plate Pressure (kPa): 259.0

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	433.0	--	--	--	12.3°	2.320	.45
0.180	G.S. (thawed)	61.8	-102.8	--	--	10.5 kPa	1.517	.35
0.228	G.S. (thawed)	45.6	- 48.15	--	--	12.0 kPa	1.525	.35
0.332	G.S. (thawed)	40.4	- 42.24	--	--	10.0 kPa	1.516	.35
0.734	G.S. (rec.)	37.8	- 58.86	--	--	1.5 kPa	1.456	.35
1.524	Subgrade	166.4	--	--	--	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

12 February 1979 (Day 43)

Plate Pressure (kPa): 280.0 / 560.2

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	15019.0	--	15019.0	--	-8.8°	2.320	.30
0.100	G.S. (frozen)	45561.3	τ_{oct}=52.73	27325.7	τ_{oct}=111.60	-7.5°	1.516	.35
0.240	G.S. (frozen)	13353.4	τ_{oct}=29.73	8800.7	τ_{oct}= 54.79	-251°	1.524	.35
0.600	G.S. (rec.)	31.4	- 37.69	32.4	- 40.61	10.0 kPa	1.516	.35
0.524	G.S. (rec.)	38.0	- 59.39	38.7	- 62.11	3.9 kPa	1.475	.35
1.524	Subgrade	164.7	- 62.88	168.8	- 64.57	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

6 March 1979 (Day 65)

Plate Pressure (kPa): 103.3 / 257.5

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	7443.0	--	7433.0	--	4.8°	2.320	.40
0.200	G.S. (thawed)	34.8	- 58.11	53.6	-148.1	0.0 kPa	1.446	.35
0.480	G.S. (frozen)	34.8	τ_{oct}= 5.10	3951.7	τ_{oct}= 13.94	-0.4 kPa	1.446	.35
0.794	G.S. (frozen)	7851.6	50.64	36.1	- 52.65	1.9 kPa	1.460	.35
1.524	Subgrade	161.8	- 60.82	163.9	- 61.31	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

13 March 1979 (Day 72)

Plate Pressure (kPa): 259.0 / 583.0

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	10382.2	--	10382.0	--	-0.8°	2.320	.35
0.070	G.S. (frozen)	794.6	τ_{oct}=146.33	559.9	τ_{oct}=244.53	-0.4°	1.475	.35
0.330	G.S. (thawed)	33.7	- 41.38	44.6	- 76.22	4.2 kPa	1.478	.35
0.280	G.S. (thawed)	37.4	- 41.42	43.2	- 56.45	7.8 kPa	1.502	.40
0.794	G.S. (rec.)	37.3	- 56.78	39.2	- 64.01	0.0 kPa	1.445	.35
1.524	Subgrade	165.2	- 62.64	169.6	- 65.03	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

21 March 1979 (Day 80)

Plate Pressure (kPa): 268.6 / 503.0

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	7835.0	--	7835.0	--	4.0°	2.320	.40
0.240	G.S. (thawed)	54.1	-104.10	72.1	-194.9	5.9 kPa	1.488	.35
0.410	G.S. (frozen)	4429.1	τ_{oct}=11.79	2790.7	τ_{oct}= 23.29	-0.4°	1.490	.35
0.734	G.S. (rec.)	36.9	- 55.26	37.9	-59.91	1.9 kPa	1.459	.35
1.524	Subgrade	165.3	- 62.70	169.7	-65.03	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

28 March 1979 (Day 87)

Plate Pressure (kPa): 267.2 / 548.2

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	10466.0	--	10466.0	--	-0.95°	2.320	.35
0.091	G.S. (frozen)	942.4	τ_{oct}=113.91	662.0	τ_{oct}=191.18	-0.4 kPa	1.496	.35
0.265	G.S. (thawed)	45.6	68.69	64.1	143.50	6.6 kPa	1.494	.35
0.384	G.S. (rec.)	6648.3	τ_{oct}= 8.61	3686.5	τ_{oct}= 20.44	-0.6°	1.489	.35
0.794	G.S. (rec.)	36.8	- 54.92	38.0	- 59.41	0.0 kPa	1.444	.35
1.524	Subgrade	164.9	- 62.48	168.8	- 64.54	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

4 April 1979 (Day 94)

Plate Pressure (kPa): 259.0 / 533.1

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	9391.0	--	9391.0	--	1.0°	2.320	.35
0.484	G.S. (thawed)	46.9	- 67.68	62.9	-128.20	7.8 kPa	1.501	.35
0.198	G.S. (frozen)	4057.5	τ_{oct}=13.40	2398.6	τ_{oct}= 29.98	-0.4°	1.497	.35
0.058	G.S. (thawed)	34.9	- 45.53	39.1	- 58.18	3.9 kPa	1.493	.40
0.734	G.S. (rec.)	37.6	- 57.81	39.4	- 64.87	0.0 kPa	1.440	.35
1.524	Subgrade	165.7	- 62.86	169.9	- 65.18	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

24 April 1979 (Day 114)

Plate Pressure (kPa): 256.3 / 535.9

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5531.0	--	5531.0	--	9.1°	2.320	.45
0.408	G.S. (thawed)	51.1	- 62.42	68.2	-116.80	11.8 kPa	1.524	.35
0.332	G.S. (thawed)	40.1	- 42.29	44.9	- 53.88	9.8 kPa	1.515	.35
0.734	G.S. (thawed)	37.9	- 58.92	39.5	- 65.38	2.5 kPa	1.463	.35
1.524	Subgrade	166.5	- 63.35	170.5	- 15.52	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

8 May 1979 (Day 128)

Plate Pressure (kPa): 261.8 / 548.2

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	3117.0	--	3117.0	--	16.25°	2.320	.50
0.408	G.S. (thawed)	53.5	- 69.10	71.7	-130.10	11.8 kPa	1.524	.50
0.332	G.S. (thawed)	40.4	- 42.83	45.2	- 54.79	9.8 kPa	1.515	.35
0.734	G.S. (rec.)	37.9	- 59.11	39.6	- 65.73	2.8 kPa	1.466	.35
1.524	Subgrade	166.7	- 63.43	170.8	- 65.66	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

30 May 1979 (Day 150)

Plate Pressure (kPa): 296.0 / 557.8

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	2970.0	--	2970.0	--	16.8°	2.320	.50
0.408	G.S. (thawed)	52.8	- 76.75	68.1	-132.90	9.8 kPa	1.515	.35
0.332	G.S. (thawed)	39.4	- 44.76	43.7	- 56.90	8.8 kPa	1.506	.35
0.734	G.S. (rec.)	38.0	- 59.60	39.6	- 65.71	0.0 kPa	1.444	.35
1.524	Subgrade	166.4	- 63.27	170.2	- 65.31	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

25 July 1979 (Day 206)

Plate Pressure (kPa): 283.7 / 582.5

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	1027.0	--	1027.0	--	27.55°	2.320	.50
0.408	G.S. (thawed)	63.8	- 85.16	85.2	-158.90	14.3 kPa	1.532	.35
0.332	G.S. (thawed)	43.6	- 43.77	48.8	- 55.85	12.0 kPa	1.525	.35
0.734	G.S. (rec.)	38.1	- 59.86	39.9	- 66.78	3.5 kPa	1.471	.35
1.524	Subgrade	167.4	- 63.81	171.7	- 66.15	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

27 September 1979 (Day 270)

Plate Pressure (kPa): 286.4 / 594.8

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	4366.0	--	4366.0	--	12.2°	2.320	.45
0.108	G.S. (thawed)	64.5	-112.80	89.5	-228.40	10.5 kPa	1.517	.35
0.228	G.S. (thawed)	46.8	- 50.99	58.0	- 80.94	12.0 kPa	1.525	.35
0.332	G.S. (thawed)	40.9	- 43.43	45.9	- 55.75	10.0 kPa	1.516	.35
0.734	G.S. (rec.)	38.0	- 59.51	39.8	- 66.54	1.5 kPa	1.456	.35
1.524	Subgrade	166.8	- 63.47	171.2	- 65.86	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

19 November 1979 (Day 323)

Plate Pressure (kPa): 376.8 / 590.7

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	6715.0	--	6715.0	--	6.35°	2.320	.40
0.108	G.S. (thawed)	62.3	- 94.43	87.2	-195.50	12.0 kPa	1.525	.35
0.228	G.S. (thawed)	42.8	- 47.86	53.3	- 77.09	10.0 kPa	1.516	.35
0.332	G.S. (thawed)	38.3	- 42.99	43.2	- 55.85	8.0 kPa	1.504	.35
0.734	G.S. (rec.)	37.9	- 59.02	39.8	- 66.25	0.0 kPa	1.444	.35
1.524	Subgrade	166.1	- 63.14	17072	- 65.57	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

* Notes:

(1) Moduli, stresses, and strains calculated by NELAPAV

(2) M_r = resilient modulus, J_1 = first stress invariant or bulk stress, ψ = moisture tension, γ_d = dry unit weight, μ_r = resilient Poisson's ratio

(3) M_r and J_1 are calculated at r=0 and center of respective layer

(4) G.S. refers to Graves sand

(5) τ_{oct} = octahedral shear stress (kPa)

(5) Negative normal stresses and strains are compressive

Tangential Strain ϵ_t (r = 0, z = .05) and Vertical Strain ϵ_v (r = 0, z = 1.524)

	30 Oct	12 Feb	6 Mar	13 Mar	21 Mar	28 Mar	4 Apr	24 Apr	8 May	30 May	25 Jul	27 Sept	19 Nov
ϵ_t (low pressure):	3.257×10^{-4}	2.452×10^{-5}	9.817×10^{-4}	1.213×10^{-4}	2.381×10^{-4}	7.391×10^{-5}	2.344×10^{-4}	3.019×10^{-4}	3.937×10^{-4}	4.586×10^{-4}	5.669×10^{-4}	3.534×10^{-4}	2.79×10^{-4}
(high pressure):	--	-5.834×10^{-5}	2.107×10^{-4}	2.938×10^{-4}	3.973×10^{-4}	1.828×10^{-4}	4.318×10^{-4}	5.541×10^{-4}	7.047×10^{-4}	7.535×10^{-4}	9.213×10^{-4}	6.232×10^{-4}	5.311×10^{-4}
ϵ_v (low pressure):	-1.308×10^{-4}	-1.150×10^{-4}	-1.122×10^{-4}	-1.331×10^{-4}	-1.171×10^{-4}	-1.162×10^{-4}	-1.240×10^{-4}	-1.318×10^{-4}	-1.324×10^{-4}	-1.350×10^{-4}	-1.339×10^{-4}	-1.339×10^{-4}	-1.330×10^{-4}
(high pressure):	--	-1.184×10^{-4}	-1.157×10^{-4}	-1.515×10^{-4}	-1.244×10^{-4}	-1.244×10^{-4}	-1.387×10^{-4}	-1.502×10^{-4}	-1.523×10^{-4}	-1.523×10^{-4}	-1.531×10^{-4}	-1.538×10^{-4}	-1.535×10^{-4}

Table D2b. Resilient moduli and supporting data calculated by NELAPAV for Graves sand test section, 1980.

25 February 1980 (Day 56)

Plate Pressure (kPa): 261.0 | 566.0

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	12679.0	--	12679.0	--	-0.25°	2.320	.35
0.350	G.S. (frozen)	1489.0	τ_{oct}=43.59	917.4	τ_{oct}= 88.66	-0.25°	1.497	.35
0.300	G.S. (rec.)	28.7	- 49.96	31.4	- 37.82	11.5 kPa	1.522	.35
0.300	G.S. (rec.)	33.0	- 42.57	34.7	- 47.97	2.0 kPa	1.460	.35
0.524	G.S. (rec.)	38.1	- 59.78	39.3	- 64.30	2.0 kPa	1.460	.35
1.524	Subgrade	165.3	- 62.69	169.3	- 64.84	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

12 March 1980 (Day 72)

Plate Pressure (kPa): 250.0 | 550.0

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	7377.0	--	7377.0	--	7.0°	2.320	.40
0.100	G.S. (thawed)	66.5	-233.50	96.7	- 52.80	0.0 kPa	1.444	.35
0.250	G.S. (frozen)	1723.3	τ_{oct}=30.35	962.4	τ_{oct}= 71.30	-0.1°	1.449	.35
0.600	G.S. (rec.)	31.5	- 37.95	34.3	- 46.47	6.0 kPa	1.490	.35
0.524	G.S. (rec.)	38.2	- 60.11	39.6	- 65.59	0.0 kPa	1.444	.35
1.524	Subgrade	164.5	- 62.25	168.6	- 64.47	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

19 March 1980 (Day 79)

Plate Pressure (kPa): 267.0 | ______

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	5918.0	--	--	--	9.95°	2.320	.45
0.124	G.S. (thawed)	90.6	-458.60	--	--	0.0 kPa	1.444	.35
0.326	G.S. (frozen)	1389.4	τ_{oct}=44.93	--	--	-0.15°	1.460	.35
0.362	G.S. (rec.)	29.6	- 32.66	--	--	7.0 kPa	1.497	.35
0.762	G.S. (rec.)	36.7	- 54.54	--	--	0.0 kPa	1.444	.35
1.524	Subgrade	164.4	- 62.21	--	--	--	1.055	.35
∞	Subgrade	200.0	--	--	--	--	1.055	.35

22 March 1980 (Day 82)

Plate Pressure (kPa): 185.0 | ______

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	8958.0	--	--	--	4.4°	2.320	.40
0.350	G.S. (thawed)	31.0	- 44.85	--	--	0.0 kPa	1.444	.35
0.300	G.S. (rec.)	31.2	- 37.10	--	--	5.0 kPa	1.482	.35
0.300	G.S. (rec.)	33.7	- 44.75	--	--	0.0 kPa	1.444	.35
0.524	G.S. (rec.)	38.2	- 60.12	--	--	0.0 kPa	1.444	.35
1.524	Subgrade	165.2	- 61.55	--	--	--	1.055	.35
∞	Subgrade	200.0	--	--	--	--	1.055	.35

26 March 1980 (Day 86)

Plate Pressure (kPa): 238.0 | ______

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	6212.0	--	--	--	9.3°	2.320	.45
0.350	G.S. (thawed)	42.9	- 58.80	--	--	7.0 kPa	1.497	.35
0.250	G.S. (rec.)	32.6	- 41.05	--	--	5.0 kPa	1.482	.35
0.874	G.S. (rec.)	36.7	- 54.68	--	--	0.0 kPa	1.444	.35
1.524	Subgrade	164.6	- 62.29	--	--	--	1.055	.35
∞	Subgrade	200.0	--	--	--	--	1.055	.35

29 March 1980 (Day 89)

Plate Pressure (kPa): 159.0 | 240.0

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	6029.0	--	6029.0	--	9.7°	2.320	.45
0.350	G.S. (thawed)	37.1	- 42.97	43.97	-59.35	7.0 kPa	1.497	.35
0.250	G.S. (rec.)	30.7	- 35.68	32.5	-40.78	7.0 kPa	1.497	.35
0.250	G.S. (rec.)	32.9	- 42.06	33.9	-45.15	3.5 kPa	1.470	.35
0.624	G.S. (rec.)	37.6	- 58.07	38.2	-60.04	0.0 kPa	1.444	.35
1.524	Subgrade	163.8	- 61.85	165.0	-62.50	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

3 April 1980 (Day 94)

Plate Pressure (kPa): 200.0 | 255.0

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	4150.0	--	4150.0	--	14.7°	2.320	.45
0.350	G.S. (thawed)	43.0	- 55.36	47.2	-67.39	8.0 kPa	1.540	.35
0.362	G.S. (rec.)	32.1	- 39.57	33.1	-42.56	7.5 kPa	1.501	.35
0.381	G.S. (rec.)	35.3	- 49.76	35.7	-51.36	0.5 kPa	1.449	.35
0.381	G.S. (rec.)	39.4	- 64.78	39.7	-66.11	0.0 kPa	1.444	.35
1.524	Subgrade	165.0	- 62.52	165.8	-62.95	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

10 April 1980 (Day 101

Plate Pressure (kPa): 235.0 | 334.0

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	5021.0	--	5021.0	--	12.15°	2.320	.45
0.350	G.S. (thawed)	41.7	- 60.74	47.8	-81.76	5.5 kPa	1.485	.35
0.362	G.S. (rec.)	32.5	- 40.87	34.2	-42.16	4.0 kPa	1.475	.35
0.381	G.S. (rec.)	35.3	- 49.99	36.2	-52.84	0.0 kPa	1.444	.35
0.381	G.S. (rec.)	39.4	- 64.79	40.0	-67.17	0.0 kPa	1.444	.35
1.524	Subgrade	164.4	- 62.21	165.9	--	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

17 April 1980 (Day 108)

Plate Pressure (kPa): 230.0 | 322.0

Thickness (m)	Materials	M_r (MPa)	J_1 (kPa)	M_r (MPa)	J_1 (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	4260.0	--	4260.0	--	14.35°	2.320	.45
0.350	G.S. (thawed)	47.8	- 61.02	54.4	-80.73	10.0 kPa	1.516	.35
0.362	G.S. (rec.)	32.4	- 40.73	34.0	-45.50	8.0 kPa	1.504	.35
0.381	G.S. (rec.)	35:4	- 50.30	36.2	-52.89	0.0 kPa	1.444	.35
0.381	G.S. (rec.)	39.5	- 65.18	40.0	-67.34	0.0 kPa	1.444	.35
1.524	Subgrade	165.1	- 62.57	166.4	-63.29	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

* Notes:

(1) Moduli, stresses, and strains calculated by NELAPAV

(2) M_r = resilient modulus, J_1 = first stress invariant or bulk stress, ψ = moisture tension, γ_d = dry unit weight, μ_r = resilient Poisson's ratio

(3) M_r and J_1 are calculated at r=0 and center of respective layer

(4) G.S. refers to Graves sand

(5) τ_{oct} = octahedral shear stress (kPa)

(5) Negative normal stresses and strains are compressive

Tangential Strain ϵ_t (r = 0, z = .05) and Vertical Strain ϵ_v (r = 0, z = 1.524)

	25 Feb	12 Mar	19 Mar	22 Mar	26 Mar	29 Mar	3 Apr	10 Apr	27 Apr
ϵ_t(low pressure):	1.921×10^{-5}	1.578×10^{-4}	8.306×10^{-4}	1.989×10^{-4}	2.816×10^{-4}	2.012×10^{-4}	2.964×10^{-4}	3.172×10^{-4}	3.220×10^{-4}
(high pressure):	7.488×10^{-5}	3.067×10^{-4}	--	--	--	2.886×10^{-4}	3.642×10^{-4}	4.280×10^{-4}	4.230×10^{-4}
ϵ_v(low pressure):	-1.966×10^{-4}	-2.071×10^{-4}	-2.205×10^{-4}	-2.197×10^{-4}	-2.355×10^{-4}	-2.138×10^{-4}	-2.223×10^{-4}	-2.313×10^{-4}	-2.296×10^{-4}
(high pressure):	-2.356×10^{-4}	-2.568×10^{-4}	--	--	--	-2.339×10^{-4}	-2.336×10^{-4}	-2.548×10^{-4}	-2.493×10^{-4}

Table D3a. Resilient moduli and supporting data calculated by NELAPAV for Hart Brothers test section, 1979.

30 October 1978 (Day -63)

Plate Pressure (kPa): 243.6 / 517.3

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	2034.0	--	2034.0	--	20.9°	2.320	.50
0.250	H.B.S. (thawed)	44.8	44.11	48.9	53.44	10.0 kPa	1.840	.33
0.300	H.B.S. (thawed)	49.5	55.03	45.2	45.00	10.0 kPa	1.840	.33
0.350	H.B.S. (thawed)	77.7	159.95	65.7	110.48	9.0 kPa	1.840	.33
0.400	H.B.S. (thawed)	125.8	486.16	99.4	288.98	8.0 kPa	1.840	.33
0.174	H.B.S.	174.7	1003.42	137.4	590.33	8.0 kPa	1.840	.33
1.524	Subgrade	178.9	J_1=-73.10	182.6	J_1=-75.24	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

13 February 1979 (Day 44)

Plate Pressure (kPa): 273.7 / 511.9

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	14149.0	--	14149.0	--	-7.3°	2.320	.30
0.250	H.B.S. (frozen)	4872.5	--	4872.5	--	-8.5°	1.584	.30
0.300	H.B.S. (frozen)	3686.7	--	3686.7	--	-4.9°	1.584	.30
0.350	H.B.S. (frozen)	1561.4	--	1561.4	--	-1.0°	1.584	.30
0.400	H.B.S. (thawed)	192.5	1118.16	156.9	711.08	9.8 kPa	1.840	.33
0.174	H.B.S.	242.5	2068.86	197.7	1318.00	9.8 kPa	1.840	.33
1.524	Subgrade	172.7	J_1=-67.83	173.5	J_1=-68.87	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

6 March 1979 (Day 65)

Plate Pressure (kPa): 255.9 / 554.3

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	6876.0	--	6876.0	--	6.1°	2.320	.40
0.250	H.B.S. (thawed)	31.3	67.78	37.7	102.42	0.0 kPa	1.780	.33
0.300	H.B.S. (frozen)	40.8	--	40.8	--	0.0°	1.584	.30
0.350	H.B.S. (frozen)	449.7	--	449.7	--	-.1°	1.584	.30
0.400	H.B.S. (thawed)	134.0	465.74	107.9	288.99	10.8 kPa	1.840	.33
0.174	H.B.S.	180.6	900.32	143.0	537.74	10.8 kPa	1.840	.33
1.524	Subgrade	176.1	J_1=-69.65	179.4	J_1=-72.02	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

13 March 1979 (Day 72)

Plate Pressure (kPa): 271.0 / 572.1

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	9391.0	--	9391.0	--	1.0°	2.320	.35
0.250	H.B.S. (thawed)	40.3	118.56	52.8	215.15	0.0 kPa	1.780	.30
0.300	H.B.S. (frozen)	449.7	--	449.7	--	-.1°	1.584	.30
0.350	H.B.S. (frozen)	654.1	--	654.1	--	-.2°	1.584	.30
0.400	H.B.S. (frozen)	40.8	--	40.8	--	0.0°	1.584	.30
0.174	H.B.S.	128.1	1520.89	100.3	886.11	0.0 kPa	1.780	.33
1.524	Subgrade	171.9	J_1=-67.45	172.9	J_1=-69.56	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

21 March 1979 (Day 80)

Plate Pressure (kPa): 258.7 / 547.5

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	5653.0	--	5653.0	--	8.8°	2.320	.45
0.250	H.B.S. (thawed)	41.6	42.41	45.1	50.64	8.3 kPa	1.840	.33
0.300	H.B.S. (thawed)	37.8	53.28	35.0	44.97	3.4 kPa	1.820	.33
0.350	H.B.S. (frozen)	40.8	—	40.8	—	0.0°	1.584	.30
0.400	H.B.S. (thawed)	84.1	472.60	66.9	284.83	1.0 kPa	1.800	.33
0.174	H.B.S.	119.7	1029.92	94.9	615.84	1.0 kPa	1.800	.33
1.524	Subgrade	177.9	J_1=-70.96	179.5	J_1=-73.27	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

28 March 1979 (Day 87)

Plate Pressure (kPa): 264.2 / 554.3

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	10158.0	—	10158.0	--	-.4°	2.320	.35
0.250	H.B.S. (thawed)	41.5	96.11	47.0	126.34	7.4 kPa	1.820	.33
0.300	H.B.S. (thawed)	42.3	66.77	40.5	60.56	4.9 kPa	1.820	.33
0.350	H.B.S. (thawed)	58.3	209.97	53.0	170.16	1.0 kPa	1.800	.30
0.400	H.B.S. (frozen)	1073.5	—	1073.5	--	-.5°	1.584	.30
0.174	H.B.S.	133.2	1302.02	106.7	799.30	1.0 kPa	1.800	.33
1.524	Subgrade	178.0	J_1=-70.71	179.4	J_1=-73.14	--	1.055	.35
∞	Subgrade	200.0	—	200.0	--	--	1.055	.35

4 April 1979 (Day 94)

Plate Pressure (kPa): 253.2 / 566.6

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	6602.0	--	6602.0	--	6.6°	2.320	.40
0.250	H.B.S. (thawed)	40.5	50.63	44.8	63.33	7.4 kPa	1.820	.33
0.300	H.B.S. (thawed)	42.6	58.77	38.3	46.31	6.9 kPa	1.820	.33
0.350	H.B.S. (thawed)	55.3	170.36	46.4	115.24	2.4 kPa	1.800	.33
0.400	H.B.S. (thawed)	89.8	495.95	70.3	289.10	2.4 kPa	1.800	.33
0.174	H.B.S.	127.1	1068.11	99.2	617.14	2.4 kPa	1.800	.33
1.524	Subgrade	180.6	J_1=-72.25	181.9	J_1=-74.76	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

24 April 1979 (Day 114)

Plate Pressure (kPa): 264.2 / 551.6

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	2324.0	--	2324.0	--	19.5°	2.320	.50
0.250	H.B.S. (thawed)	45.1	43.83	48.2	50.75	10.3 kPa	1.840	.33
0.300	H.B.S. (thawed)	47.2	50.20	42.1	39.04	9.8 kPa	1.840	.33
0.350	H.B.S. (thawed)	62.3	156.42	53.1	109.85	4.9 kPa	1.820	.33
0.400	H.B.S. (thawed)	102.2	466.62	81.6	284.02	4.9 kPa	1.820	.33
0.174	H.B.S.	143.9	993.36	114.4	598.59	4.9 kPa	1.820	.33
1.524	Subgrade	178.6	J_1=-72.92	182.6	J_1=-75.20	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

7 May 1979 (Day 127)

Plate Pressure (kPa): 258.7 / 547.5

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	218.0	--	218.0	--	40.3°	2.320	.50
0.250	H.B.S. (thawed)	38.6	32.27	40.3	35.33	9.8 kPa	1.840	.33
0.300	H.B.S. (thawed)	44.1	43.16	38.7	32.39	9.8 kPa	1.840	.33
0.350	H.B.S. (thawed)	59.6	147.11	50.8	103.47	4.4 kPa	1.820	.33
0.400	H.B.S. (thawed)	98.9	449.83	78.6	270.96	4.4 kPa	1.820	.33
0.174	H.B.S.	140.3	972.86	110.8	579.34	4.4 kPa	1.820	.33
1.524	Subgrade	181.1	J_1=-72.99	184.2	J_1=-75.39	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

29 May 1979 (Day 149)

Plate Pressure (kPa): 258.7 / 559.8

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	518.0	—	518.0	—	33.5°	2.320	.50
0.250	H.B.S. (thawed)	35.6	38.04	37.9	43.62	7.4 kPa	1.820	.33
0.300	H.B.S. (thawed)	41.8	45.70	36.9	34.87	7.4 kPa	1.840	.33
0.350	H.B.S. (thawed)	58.7	147.46	49.9	102.81	3.9 kPa	1.820	.33
0.400	H.B.S. (thawed)	97.3	449.57	77.0	268.23	3.9 kPa	1.820	.33
0.174	H.B.S.	138.2	975.02	108.7	573.97	3.9 kPa	1.820	.33
1.524	Subgrade	179.5	J_1=-72.87	183.1	J_1=-75.35	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

25 July 1979 (Day 206)

Plate Pressure (kPa): 283.3 / 580.3

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	782.0	—	782.0	--	30.0°	2.320	.50
0.250	H.B.S. (thawed)	48.0	34.58	49.0	36.17	13.0 kPa	1.860	.33
0.300	H.B.S. (thawed)	49.6	43.21	43.4	32.30	11.0 kPa	1.860	.33
0.350	H.B.S. (thawed)	63.7	146.51	54.7	104.68	6.5 kPa	1.820	.33
0.400	H.B.S. (thawed)	104.5	437.78	84.1	270.88	6.5 kPa	1.820	.33
0.174	H.B.S.	146.9	928.07	117.6	1579.96	6.5 kPa	1.820	.33
1.524	Subgrade	182.5	J_1=-73.32	183.7	J_1=-75.72	—	1.055	.35
∞	Subgrade	200.0	--	200.0	—	--	1.055	.35

27 September 1979 (Day 270)

Plate Pressure (kPa): 276.5 / 584.4

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	3964.0	—	3964.0	—	13.4°	2.320	.45
0.250	H.B.S. (thawed)	45.3	45.18	48.9	53.40	10.0 kPa	1.840	.33
0.300	H.B.S. (thawed)	43.6	55.27	39.8	45.24	8.4 kPa	1.820	.33
0.350	H.B.S. (thawed)	62.4	156.15	53.2	109.87	5.0 kPa	1.820	.33
0.400	H.B.S. (thawed)	101.3	454.85	80.9	276.85	5.0 kPa	1.820	.33
0.174	H.B.S.	142.3	961.99	113.1	579.40	5.0 kPa	1.820	.33
1.524	Subgrade	181.7	J_1=-72.89	186.0	J_1=-75.31	--	1.055	.35
∞	Subgrade	200.0	—	200.0	--	—	1.055	.35

20 November 1979 (Day 324)

Plate Pressure (kPa): 273.7 / 584.4

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ψ (kPa)	γ_d (Mg/m^3)	μ_r
0.050	Asphalt Concrete	6969.0	—	6969.0	—	5.8°	2.320	.40
0.250	H.B.S. (thawed)	48.5	52.46	54.4	67.68	10.0 kPa	1.840	.33
0.300	H.B.S. (thawed)	49.6	65.23	46.9	57.74	10.0 kPa	1.820	.33
0.350	H.B.S. (thawed)	86.4	161.45	73.6	113.47	12.0 kPa	1.840	.33
0.400	H.B.S. (thawed)	142.9	454.18	113.3	272.17	13.0 kPa	1.840	.33
0.174	H.B.S.	194.0	893.28	153.1	528.65	13.0 kPa	1.840	.33
1.524	Subgrade	179.0	J_1=-73.15	184.6	J_1=-75.48	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	—	1.055	.35

Notes:

(1) Moduli, stresses, and strains calculated by NELAPAV

(2) M_r = resilient modulus, J_1 = first stress invariant or bulk stress, J_2 = second stress invariant, τ_{oct} = octahedral shear stress, ψ = moisture tension, γ_d = dry unit weight, μ_r = resilient Poisson's ratio

(3) M_r and J_2/τ_{oct} are calculated at r=0 and center of respective layer

(4) H.B.S. refers to Hart Brothers sand (never frozen except as noted)

(5) Negative normal stresses and strains are compressive.

Tangential Strain ϵ_t (r = 0, z = .05) and Vertical Strain ϵ_v (r = 0, z = 1.524)

	30 Oct	13 Feb	6 Mar	13 Mar	21 Mar	28 Mar	4 Apr	24 Apr	7 May	29 May	25 Jul	27 Sept	20 Nov
ϵ_t(low pressure):	4.791×10^{-4}	2.279×10^{-6}	3.146×10^{-4}	2.608×10^{-4}	3.264×10^{-4}	2.425×10^{-4}	2.989×10^{-4}	4.894×10^{-4}	9.620×10^{-4}	9.348×10^{-4}	7.415×10^{-4}	4.051×10^{-4}	2.901×10^{-4}
(high pressure):	9.789×10^{-4}	4.253×10^{-6}	6.446×10^{-4}	4.542×10^{-4}	6.759×10^{-4}	4.936×10^{-4}	6.539×10^{-4}	9.975×10^{-4}	1.948×10^{-3}	1.936×10^{-3}	1.500×10^{-3}	8.365×10^{-4}	5.987×10^{-4}
ϵ_v(low pressure):	-1.381×10^{-4}	-1.240×10^{-4}	-1.376×10^{-4}	-1.279×10^{-4}	-1.398×10^{-4}	-1.335×10^{-4}	-1.405×10^{-4}	-1.397×10^{-4}	-1.424×10^{-4}	-1.413×10^{-4}	-1.436×10^{-4}	-1.426×10^{-4}	-1.396×10^{-4}
(high pressure):	-1.595×10^{-4}	-1.290×10^{-4}	-1.578×10^{-4}	-1.375×10^{-4}	-1.598×10^{-4}	-1.459×10^{-4}	-1.617×10^{-4}	-1.618×10^{-4}	-1.643×10^{-4}	-1.648×10^{-4}	-1.646×10^{-4}	-1.655×10^{-4}	-1.637×10^{-4}

Table D3b. Resilient moduli and supporting data calculated by NELAPAV for Hart Brothers test section, 1980.

25 February 1980 (Day 56)

Plate Pressure (kPa): 279.0 | 605.0

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m^3)	ν_r
0.050	Asphalt Concrete	12168.0	--	12168.0	--	.3°	2.320	.35
0.250	H.B.S. (frozen)	670.4	39.44	793.3	62.55	-.6°	1.584	.30
0.300	H.B.S. (frozen)	281.1	13.01	446.8	42.28	-.3°	1.584	.30
0.224	H.B.S. (thawed)	42.5	221.35	37.4	167.42	1.0 kPa	1.715	.33
0.700	H.B.S.	79.2	876.02	65.2	569.77	1.0 kPa	1.715	.33
1.524	Subgrade	179.9	J_1=-67.97	176.7	J_1=-70.05	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

12 March 1980 (Day 72)

Plate Pressure (kPa): 255.0 | 599.0

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(ϕ (kPa)	γ_d (Mg/m^3)	ν_r
0.050	Asphalt Concrete	7001.0	—	7001.0	—	7.7°	2.320	.40
0.250	H.B.S. (frozen)	122.5	11.39	180.8	29.16	-.1°	1.584	.30
0.300	H.B.S. (frozen)	100.3	6.54	218.4	48.69	-.1°	1.584	.30
0.224	H.B.S. (thawed)	35.4	171.54	31.8	125.01	0.0 kPa	1.715	.33
0.700	H.B.S.	65.2	666.02	53.7	397.65	0.0 kPa	1.715	.33
1.524	Subgrade	170.7	J_1=-68.06	174.5	J_1=-70.48	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

19 March 1980 (Day 79)

Plate Pressure (kPa): 266.0 | 382.0

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m^3)	ν_r
0.050	Asphalt Concrete	5431.0	—	5431.0	—	11.1°	2.320	.45
0.250	H.B.S. (thawed)	23.1	111.25	26.1	145.90	0.0 kPa	1.651	.33
0.300	H.B.S. (frozen)	249.7	70.62	237.7	61.71	-.1°	1.584	.30
0.224	H.B.S. (frozen)	208.5	41.55	170.4	24.79	-.1°	1.584	.30
0.700	H.B.S.	73.6	508.77	65.3	389.99	2.0 kPa	1.750	.33
1.524	Subgrade	173.8	J_1=-68.46	175.1	J_1=-69.36	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

22 March 1980 (Day 82)

Plate Pressure (kPa): 197.0 | 352.0

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m^3)	ν_r
0.050	Asphalt Concrete	8958.0	--	8958.0	--	4.4°	2.320	.40
0.250	H.B.S. (thawed)	18.4	67.17	20.9	89.02	0.0 kPa	1.651	.33
0.300	H.B.S. (thawed)	40.6	71.57	37.4	59.87	5.0 kPa	1.800	.33
0.224	H.B.S. (thawed)	45.0	171.79	39.2	126.73	2.0 kPa	1.750	.33
0.700	H.B.S.	67.6	603.41	55.6	400.28	1.0 kPa	1.715	.33
1.524	Subgrade	173.4	J_1=-69.57	175.2	J_1=-70.87	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

26 March 1980 (Day 86)

Plate Pressure (kPa): 240.0 | 414.0

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m^3)	ν_r
0.050	Asphalt Concrete	6353.0	--	6353.0	--	9.0°	2.320	.45
0.250	H.B.S. (thawed)	19.8	78.75	22.9	108.97	0.0 kPa	1.651	.33
0.300	H.B.S. (thawed)	43.1	81.78	42.4	79.02	5.0 kPa	1.800	.33
0.224	H.B.S. (frozen)	244.8	66.89	188.9	32.87	-.1°	1.584	.30
0.700	H.B.S.	63.9	545.76	53.7	371.72	1.0 kPa	1.715	.33
1.524	Subgrade	173.0	J_1=-69.27	176.1	J_1=-70.75	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

29 March 1980 (Day 89)

Plate Pressure (kPa): 262.0 | 360.0

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m^3)	ν_r
0.050	Asphalt Concrete	6644.0	--	6644.0	--	8.4°	2.320	.45
0.250	H.B.S. (thawed)	20.0	80.83	21.6	97.79	0.0 kPa	1.651	.33
0.300	H.B.S. (thawed)	45.8	59.16	43.6	53.09	9.0 kPa	1.820	.33
0.224	H.B.S. (thawed)	42.7	142.79	39.8	122.25	3.0 kPa	1.750	.33
0.700	H.B.S.	62.6	487.35	56.5	388.40	2.0 kPa	1.715	.33
1.524	Subgrade	174.8	J_1=-70.23	177.5	J_1=-71.04	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

3 April 1980 (Day 94)

Plate Pressure (kPa): 252.0 | 351.0

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m^3)	ν_r
0.050	Asphalt Concrete	5232.0	—	5232.0	--	11.6°	2.320	.45
0.250	H.B.S. (thawed)	27.6	67.08	29.4	76.99	0.0 kPa	1.750	.33
0.300	H.B.S. (thawed)	45.2	53.16	42.4	46.32	10.0 kPa	1.820	.33
0.224	H.B.S. (thawed)	42.3	144.35	39.2	122.34	4.0 kPa	1.750	.33
0.700	H.B.S.	63.3	515.99	56.8	406.37	1.5 kPa	1.715	.33
1.524	Subgrade	175.4	J_1=-70.60	176.2	J_1=-71.41	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

10 April 1980 (Day 101)

Plate Pressure (kPa): 247.0 | 354.0

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m^3)	ν_r
0.050	Asphalt Concrete	5078.0	—	5078.0	--	12.0°	2.320	.45
0.250	H.B.S. (thawed)	25.8	57.80	27.4	65.89	0.0 kPa	1.750	.33
0.300	H.B.S. (thawed)	33.3	58.92	31.6	52.55	7.0 kPa	1.780	.33
0.224	H.B.S. (thawed)	39.3	145.48	36.3	122.00	0.0 kPa	1.750	.33
0.700	H.B.S.	60.4	515.97	53.7	397.88	0.0 kPa	1.715	.33
1.524	Subgrade	174.0	J_1=-70.35	176.8	J_1=-71.25	--	1.055	.35
∞	Subgrade	200.0	—	200.0	--	--	1.055	.35

17 April 1980 (Day 108)

Plate Pressure (kPa): 238.0 | 331.0

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m^3)	ν_r
0.050	Asphalt Concrete	4028.0	—	4028.0	--	15.1°	2.320	.45
0.250	H.B.S. (thawed)	26.9	62.92	28.6	72.29	1.0 kPa	1.750	.33
0.300	H.B.S. (thawed)	41.9	57.64	39.9	51.79	9.0 kPa	1.800	.33
0.224	H.B.S. (thawed)	49.6	142.12	46.0	120.53	4.0 kPa	1.780	.33
0.700	H.B.S.	74.6	523.14	66.8	410.74	2.0 kPa	1.750	.33
1.524	Subgrade	175.1	J_1=-70.97	177.6	J_1=-71.72	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

Notes: (1) Moduli, stresses, and strains calculated by NELAPAV

(2) M_r = resilient modulus, J_1 = first stress invariant or bulk stress, J_2 = second stress invariant, τ_{oct} = octahedral shear stress, ϕ = moisture tension, γ_d = dry unit weight, ν_r = resilient Poisson's ratio

(3) M_r and J_2/τ_{oct} are calculated at r=0 and center of respective layer

(4) H.B.S. refers to Hart Brothers sand (never frozen except as noted)

(5) Negative normal stresses and strains are compressive.

Tangential Strain ϵ_t (r = 0, z = .05) and Vertical Strain ϵ_v (r = 0, z = 1.524)

	25 Feb	12 Mar	19 Mar	22 Mar	26 Mar	29 Mar	3 Apr	10 Apr	17 Apr
ϵ_t(low pressure):	4.940×10^{-4}	1.737×10^{-4}	3.763×10^{-4}	2.327×10^{-4}	3.371×10^{-4}	3.591×10^{-4}	3.700×10^{-4}	3.843×10^{-4}	4.151×10^{-4}
(high pressure):	9.242×10^{-5}	3.147×10^{-4}	5.208×10^{-4}	4.072×10^{-4}	5.612×10^{-4}	4.860×10^{-4}	5.083×10^{-4}	5.439×10^{-4}	5.676×10^{-4}
ϵ_v(low pressure):	-1.280×10^{-4}	-1.315×10^{-4}	-1.361×10^{-4}	-1.334×10^{-4}	-1.356×10^{-4}	-1.388×10^{-4}	-1.379×10^{-4}	-1.365×10^{-4}	-1.365×10^{-4}
(high pressure):	-1.361×10^{-4}	-1.428×10^{-4}	-1.435×10^{-4}	-1.441×10^{-4}	-1.478×10^{-4}	-1.454×10^{-4}	-1.441×10^{-4}	-1.456×10^{-4}	-1.447×10^{-4}

Table D4a. Resilient moduli and supporting data calculated by NELAPAV for Hyannis sand test section, 1979.

31 October 1978 (Day -62)

Plate Pressure (kPa): 213.5 | 532.4

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	7551.0	--	7551.0	--	4.0°	2.320	.40
0.250	H.S. (thawed)	62.2	50.90	69.0	75.27	8.0 kPa	1.690	.35
0.300	H.S. (thawed)	63.9	56.45	60.0	44.47	8.0 kPa	1.690	.35
0.300	H.S. (thawed)	82.3	147.41	72.6	93.02	8.0 kPa	1.690	.35
0.200	H.S. (thawed)	100.2	364.73	86.4	207.06	6.0 kPa	1.670	.40
0.424	H.S.	123.7	804.23	103.5	410.63	6.0 kPa	1.670	.40
1.524	Subgrade	126.1	168.72	123.9	160.53	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

12 February 1979 (Day 43)

Plate Pressure (kPa): 273.7 | 547.5

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	15135.0	—	15135.0	—	-9.0°	2.320	.30
0.250	H.S. (frozen)	29993.9	—	29993.9	—	-8.7°	1.366	.30
0.300	H.S. (frozen)	17448.4	—	17448.4	—	-4.7°	1.366	.30
0.300	H.S. (frozen)	447.1	—	447.1	—	-1.0°	1.366	.30
0.200	H.S. (frozen)	21.0	—	21.0	—	0.0°	1.366	.30
0.424	H.S.	188.7	3404.69	161.0	1865.25	8.0 kPa	1.690	.35
1.524	Subgrade	123.2	157.88	123.1	157.49	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

7 March 1979 (Day 66)

Plate Pressure (kPa): 261.4 | 566.6

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	7835.0	—	7835.0	—	4.0°	2.320	.40
0.250	H.S. (frozen)	21.0	—	21.0	—	0.0°	1.366	.30
0.300	H.S. (frozen)	21.0	—	21.0	—	0.0°	1.366	.30
0.300	H.S. (thawed)	79.0	125.67	73.6	96.01	8.0 kPa	1.690	.35
0.200	H.S. (thawed)	94.7	249.87	84.2	159.96	8.0 kPa	1.690	.35
0.424	H.S.	115.9	538.09	99.9	306.09	8.0 kPa	1.690	.35
1.524	Subgrade	121.2	150.66	120.3	147.67	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

12 March 1979 (Day 71)

Plate Pressure (kPa): 271.0 | 572.1

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	7299.0	—	7299.0	—	5.1°	2.320	.40
0.100	H.S. (frozen)	21.0	—	21.0	—	0.0°	1.366	.30
0.450	H.S. (frozen)	1966.8	—	1966.8	—	-0.4°	1.366	.30
0.300	H.S. (frozen)	1085.1	—	1085.1	—	-0.2°	1.366	.30
0.200	H.S. (frozen)	21.0	—	21.0	—	0.0°	1.366	.35
0.424	H.S.	144.9	1252.68	124.1	695.67	8.0 kPa	1.690	.35
1.524	Subgrade	122.4	154.81	122.4	155.13	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

20 March 1979 (Day 79)

Plate Pressure (kPa): 261.4 | 547.5

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	1976.0	—	1976.0	—	21.2°	2.320	.50
0.250	H.S. (thawed)	67.6	92.40	78.0	158.79	4.0 kPa	1.670	.40
0.300	H.S. (thawed)	72.5	106.57	78.4	143.80	6.0 kPa	1.670	.40
0.300	H.S. (frozen)	1085.1	—	1085.1	—	-0.2°	1.366	.30
0.200	H.S. (thawed)	103.6	351.06	93.1	233.90	8.0 kPa	1.690	.35
0.424	H.S.	125.0	714.78	109.0	426.05	8.0 kPa	1.690	.35
1.524	Subgrade	122.9	156.73	123.4	158.62	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

27 March 1979 (Day 86)

Plate Pressure (kPa): 261.4 | 547.5

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5945.0	—	5945.0	—	8.1°	2.320	.45
0.250	H.S. (thawed)	65.5	82.15	73.1	124.25	4.0 kPa	1.670	.40
0.300	H.S. (thawed)	61.8	64.05	60.8	60.11	4.4 kPa	1.670	.40
0.300	H.S. (thawed)	78.7	124.30	71.6	86.82	8.0 kPa	1.690	.35
0.200	H.S. (thawed)	97.2	275.89	86.0	173.60	8.0 kPa	1.690	.35
0.424	H.S.	120.6	625.43	104.3	360.60	8.0 kPa	1.690	.35
1.524	Subgrade	125.8	167.51	122.1	153.90	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

3 April 1979 (Day 93)

Plate Pressure (kPa): 249.1 | 551.6

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	6602.0	—	6602.0	—	6.6°	2.320	.40
0.250	H.S. (thawed)	65.1	80.25	73.2	125.09	4.0 kPa	1.670	.40
0.300	H.S. (thawed)	61.7	65.30	60.6	61.04	4.0 kPa	1.670	.40
0.300	H.S. (thawed)	79.4	128.27	71.7	86.94	8.0 kPa	1.690	.35
0.200	H.S. (thawed)	98.1	286.08	86.0	173.28	8.0 kPa	1.690	.35
0.424	H.S.	121.9	650.87	104.2	359.18	8.0 kPa	1.690	.35
1.524	Subgrade	125.9	168.09	122.1	153.82	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

23 April 1979 (Day 113)

Plate Pressure (kPa): 258.7 | 542.0

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	936.0	—	936.0	—	28.4°	2.320	.50
0.250	H.S. (thawed)	64.5	68.64	70.6	96.62	6.0 kPa	1.670	.40
0.300	H.S. (thawed)	57.7	38.80	53.6	29.41	7.8 kPa	1.690	.35
0.300	H.S. (thawed)	76.7	131.99	70.9	97.95	6.0 kPa	1.670	.40
0.200	H.S. (thawed)	94.0	285.40	83.9	185.40	6.0 kPa	1.670	.40
0.424	H.S.	116.4	553.80	101.1	376.34	6.0 kPa	1.670	.40
1.524	Subgrade	125.5	166.50	123.5	158.96	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

7 May 1979 (Day 127)

Plate Pressure (kPa): 268.3 | 539.3

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	437.0	—	437.0	—	34.9°	2.320	.50
0.250	H.S. (thawed)	63.3	67.48	70.1	98.98	5.0 kPa	1.670	.40
0.300	H.S. (thawed)	60.4	49.71	58.9	45.01	6.8 kPa	1.670	.40
0.300	H.S. (thawed)	75.2	111.00	68.9	79.56	7.4 kPa	1.690	.35
0.200	H.S. (thawed)	93.5	255.82	83.4	166.20	7.0 kPa	1.690	.35
0.424	H.S.	116.7	592.70	101.7	352.06	7.0 kPa	1.690	.35
1.524	Subgrade	125.7	167.26	122.8	156.37	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

29 May 1979 (Day 149)

Plate Pressure (kPa): 271.0 | 557.1

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	571.0	—	571.0	—	32.7°	2.320	.50
0.250	H.S. (thawed)	62.3	67.95	68.9	99.52	4.0 kPa	1.670	.40
0.300	H.S. (thawed)	58.7	47.84	56.9	42.63	6.0 kPa	1.670	.40
0.300	H.S. (thawed)	72.8	122.71	67.5	92.11	4.0 kPa	1.670	.40
0.200	H.S. (thawed)	89.5	267.58	80.3	156.80	4.0 kPa	1.670	.40
0.424	H.S.	111.0	605.48	97.0	363.44	4.0 kPa	1.670	.40
1.524	Subgrade	123.7	159.65	123.2	157.84	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

24 July 1979 (Day 205)

Plate Pressure (kPa): 271.0 | 579.0

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	416.0	—	416.0	—	35.3°	2.320	.50
0.250	H.S. (thawed)	67.7	106.50	76.7	171.50	2.0 kPa	1.650	.45
0.300	H.S. (thawed)	58.4	47.17	56.8	42.25	6.0 kPa	1.670	.40
0.300	H.S. (thawed)	75.9	107.85	69.0	75.40	8.0 kPa	1.690	.35
0.200	H.S. (thawed)	94.7	250.40	83.8	157.62	8.0 kPa	1.690	.35
0.424	H.S.	118.4	581.76	102.0	331.56	8.0 kPa	1.690	.35
1.524	Subgrade	125.6	166.88	123.5	159.10	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

27 September 1979 (Day 270)

Plate Pressure (kPa): 280.6 | 596.8

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	936.0	--	936.0	—	28.4°	2.320	.50
0.250	H.S. (thawed)	68.4	110.85	77.1	175.02	2.0 kPa	1.650	.45
0.300	H.S. (thawed)	56.8	46.34	55.3	41.87	4.5 kPa	1.670	.40
0.300	H.S. (thawed)	74.5	143.31	70.4	115.79	3.0 kPa	1.650	.45
0.200	H.S. (thawed)	92.6	229.74	92.6	145.45	8.0 kPa	1.690	.35
0.424	H.S.	116.0	539.43	116.0	310.57	8.0 kPa	1.690	.35
1.524	Subgrade	125.3	165.49	125.3	157.25	—	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

19 November 1979 (Day 323)

Plate Pressure (kPa): 273.7 | 589.9

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	6334.0	—	6334.0	—	7.2°	2.320	.40
0.250	H.S. (thawed)	68.8	55.42	75.1	77.11	12.0 kPa	1.710	.35
0.300	H.S. (thawed)	67.7	52.15	64.3	42.97	12.0 kPa	1.710	.35
0.300	H.S. (thawed)	86.1	129.72	77.9	88.89	12.0 kPa	1.710	.35
0.200	H.S. (thawed)	101.8	283.65	89.5	174.36	10.0 kPa	1.690	.35
0.424	H.S.	121.5	642.83	104.5	362.79	8.0 kPa	1.690	.35
1.524	Subgrade	126.2	168.97	123.1	157.55	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

Notes:
(1) Moduli, stresses, and strains calculated by NELAPAV
(2) M_r = resilient modulus, J_1 = first stress invariant or bulk stress, J_2 = second stress invariant, τ_{oct} = octahedral shear stress, ϕ = moisture tension, γ_d = dry unit weight, μ_r = resilient Poisson's ratio
(3) M_r and J_2/τ_{oct} are calculated at r=0 and center of respective layer
(4) H.S. refers to Hyannis sand (never frozen except as noted)
(5) Negative normal stresses and strains are compressive.

Tangential Strain ε_t (r = 0, z = .05) and Vertical Strain ε_v (r = 0, z = 1.524)

	31 Oct	12 Feb	7 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	7 May	29 May	24 Jul	27 Sept	19 Nov
ε_t(low pressure):	1.955×10^{-4}	1.899×10^{-6}	3.461×10^{-4}	3.363×10^{-4}	4.159×10^{-4}	2.637×10^{-4}	2.437×10^{-4}	5.415×10^{-4}	6.495×10^{-4}	6.437×10^{-4}	6.550×10^{-4}	5.814×10^{-4}	2.510×10^{-4}
(high pressure):	4.625×10^{-4}	3.648×10^{-6}	7.510×10^{-4}	7.100×10^{-4}	7.983×10^{-4}	5.308×10^{-4}	5.178×10^{-4}	1.062×10^{-3}	1.185×10^{-3}	1.212×10^{-3}	1.242×10^{-3}	1.131×10^{-4}	5.255×10^{-4}
ε_v(low pressure):	-1.793×10^{-4}	-1.357×10^{-4}	-1.824×10^{-4}	-1.476×10^{-4}	-1.742×10^{-4}	-1.878×10^{-4}	-1.856×10^{-4}	-1.901×10^{-4}	-1.907×10^{-4}	-1.922×10^{-4}	-1.910×10^{-4}	-1.994×10^{-4}	-1.886×10^{-4}
(high pressure):	-2.356×10^{-4}	-1.415×10^{-4}	-2.436×10^{-4}	-1.675×10^{-4}	-2.153×10^{-4}	-2.355×10^{-4}	-2.361×10^{-4}	-2.443×10^{-4}	-2.383×10^{-4}	-2.499×10^{-4}	-2.476×10^{-4}	-2.456×10^{-4}	-2.390×10^{-4}

Table D4b. Resilient moduli and supporting data calculated by NELAPAV for Hyannis sand test section, 1980.

25 February 1980 (Day 56)

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
Plate Pressure (kPa)		273		550				
0.050	Asphalt Concrete	7377.0	--	7377.0	--	7.0°	2.320	.40
0.250	H.S. (frozen)	1996.8	--	1996.8	--	-0.4°	1.366	.30
0.300	H.S. (thawed)	68.9	130.30	67.6	121.67	0.0 kPa	1.650	.45
0.300	H.S. (thawed)	92.4	227.89	83.4	154.83	8.0 kPa	1.690	.35
0.624	H.S.	128.0	775.03	111.3	460.29	8.0 kPa	1.690	.35
1.524	Subgrade	125.6	166.77	124.6	162.95	--	1.055	35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

12 March 1980 (Day 72)

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
Plate Pressure (kPa):		240		560				
0.050	Asphalt Concrete	8190.0	--	8190.0	--	5.6°	2.320	.40
0.250	H.S. (thawed)	85.6	297.37	104.8	640.12	0.0 kPa	1.366	.45
0.300	H.S. (frozen)	1996.8	--	1996.8	--	0.4°	1.366	.30
0.300	H.S. (thawed)	83.8	273.98	78.3	211.40	0.0 kPa	1.366	.45
0.624	H.S.	119.5	602.47	102.5	368.03	8.0 kPa	1.690	.35
1.524	Subgrade	122.7	156.56	121.3	151.23	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

19 March 1980 (Day 79)

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
Plate Pressure (kPa)*:		397		552				
0.050	Asphalt Concrete	5116.0	--	5116.0	--	11.9°	2.320	.45
0.250	H.S. (thawed)	76.8	196.69	82.2	255.24	0.0 kPa	1.650	.45
0.300	H.S. (thawed)	72.2	118.94	74.9	136.67	4.0 kPa	1.670	.40
0.300	H.S. (frozen)	589.7	--	589.7	--	-0.1°	1.366	.30
0.624	H.S.	106.0	383.79	100.3	310.52	8.0 kPa	1.690	.35
1.524	Subgrade	123.6	159.31	122.8	156.28	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

22 March 1980 (Day 82)

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
Plate Pressure (kPa)		196		516				
0.050	Asphalt Concrete	8958.0	--	8958.0	--	4.4°	2.320	.40
0.250	H.S. (thawed)	65.9	96.14	76.6	170.46	2.0 kPa	1.650	.45
0.300	H.S. (thawed)	60.2	59.77	59.7	57.98	4.0 kPa	1.670	.40
0.300	H.S. (thawed)	75.0	180.02	67.8	122.93	0.0 kPa	1.650	.45
0.624	H.S.	105.0	434.02	88.1	223.10	6.0 kPa	1.670	.40
1.524	Subgrade	125.2	165.29	122.7	155.99	--	1.055	35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

26 March 1980 (Day 86)

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
Plate Pressure (kPa)		244		487				
0.050	Asphalt Concrete	5595.0	--	5595.0	--	10.7°	2.320	.45
0.250	H.S. (thawed)	65.8	73.89	72.4	105.96	6.0 kPa	1.670	.40
0.300	H.S. (thawed)	61.6	57.43	59.8	51.46	6.0 kPa	1.670	.40
0.300	H.S. (frozen)	73.3	165.27	68.8	129.97	0.0 kPa	1.366	.35
0.624	H.S.	104.7	485.03	92.0	297.48	4.0 kPa	1.670	.40
1.524	Subgrade	124.1	161.11	122.3	154.59	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

29 March 1980 (Day 89)

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
Plate Pressure (kPa).		255		499				
0.050	Asphalt Concrete	5350.0	--	5350.0	--	11.3°	2.320	.45
0.250	H.S. (thawed)	63.5	73.01	70.8	110.12	4.0 kPa	1.670	.40
0.300	H.S. (thawed)	59.5	50.47	59.5	50.39	6.0 kPa	1.670	.40
0.300	H.S. (thawed)	72.2	155.89	68.4	127.22	0.0 kPa	1.650	.45
0.624	H.S.	99.4	523.94	89.0	344.22	0.0 kPa	1.650	.45
1.524	Subgrade	124.7	163.51	123.0	157.19	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

3 April 1980 (Day 94)

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
Plate Pressure (kPa):		248		466				
0.050	Asphalt Concrete	2388.0	--	2388.0	--	22.1°	2.320	.50
0.250	H.S. (thawed)	62.1	67.05	67.9	94.07	4.0 kPa	1.670	.40
0.300	H.S. (thawed)	58.3	69.22	58.2	68.76	0.0 kPa	1.650	.45
0.300	H.S. (thawed)	71.5	150.56	67.3	119.39	0.0 kPa	1.650	.45
0.624	H.S.	99.3	521.81	88.7	340.45	0.0 kPa	1.650	.45
1.524	Subgrade	124.8	163.58	123.8	157.08	--	1.055	35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

10 April 1980 (Day 101)

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
Plate Pressure (kPa).		226		475				
0.050	Asphalt Concrete	4747.0	--	4747.0	--	12.9°	2.320	.45
0.250	H.S. (thawed)	65.0	104.72	72.5	158.63	0.0 kPa	1.650	.45
0.300	H.S. (thawed)	59.1	72.78	53.9	51.63	0.0 kPa	1.650	.45
0.300	H.S. (thawed)	75.1	181.16	68.0	124.46	0.0 kPa	1.650	.45
0.624	H.S.	104.7	636.69	98.1	344.95	0.0 kPa	1.650	.45
1.524	Subgrade	124.9	164.13	122.9	156.94	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

17 April 1980 (Day 108)

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
Plate Pressure (kPa):		221		439				
0.050	Asphalt Concrete	1583.0	--	1583.0	--	27.6°	2.320	.50
0.250	H.S. (thawed)	62.0	58.92	68.0	83.70	6.0 kPa	1.670	.40
0.300	H.S. (thawed)	57.9	67.53	57.6	66.08	0.0 kPa	1.650	.45
0.300	H.S. (thawed)	72.2	156.22	67.3	119.64	0.0 kPa	1.650	.45
0.624	H.S.	101.4	564.79	89.4	350.41	0.0 kPa	1.650	.45
1.524	Subgrade	123.7	159.63	122.4	154.93	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

* Notes:
(1) Moduli, stresses, and strains calculated by NELAPAV
(2) M_r = resilient modulus, J_1 = first stress invariant or bulk stress, J_2 = second stress invariant, ϕ = moisture tension, γ_d = dry unit weight, μ_r = resilient Poisson's ratio
(3) M_r and J_1 are calculated at r=0 and center of respective layer
(4) H.S. refers to Hyannis sand
(5) τ_{oct} = octahedral shear stress (kPa)
(6) Negative normal stresses and strains are compressive

Tangential Strain ϵ_t (r = 0, z = .05) and Vertical Strain ϵ_v (r = 0, z = 1.524)

	25 Feb	12 Mar	19 Mar	22 Mar	26 Mar	29 Mar	3 Apr	10 Apr	17 Apr
ϵ_t(low pressure):	7.302×10^{-6}	1.580×10^{-4}	3.940×10^{-4}	1.601×10^{-4}	2.516×10^{-4}	2.744×10^{-4}	3.892×10^{-4}	2.575×10^{-4}	4.082×10^{-4}
(high pressure):	1.439×10^{-5}	3.386×10^{-4}	5.310×10^{-4}	4.027×10^{-4}	4.852×10^{-4}	5.138×10^{-4}	6.985×10^{-4}	5.209×10^{-4}	7.670×10^{-4}
ϵ_v(low pressure):	-1.658×10^{-4}	-1.619×10^{-4}	-1.982×10^{-4}	-1.781×10^{-4}	-1.828×10^{-4}	-1.902×10^{-4}	-1.898×10^{-4}	-1.848×10^{-4}	-1.834×10^{-4}
(high pressure):	-1.918×10^{-4}	-1.971×10^{-4}	-2.203×10^{-4}	-2.402×10^{-4}	-2.275×10^{-4}	-2.360×10^{-4}	-2.336×10^{-4}	-2.330×10^{-4}	-2.249×10^{-4}

Table D5a. Resilient moduli and supporting data calculated by NELAPAV for dense-graded stone test section, 1979.

31 October 1978 (Day 63)

	Plate Pressure (kPa):	259		547				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	6349.0	--	6349.0	--	7.2°	2.320	.40
0.250	D.G.S. (thawed)	100.8	83.09	107.3	131.82	10.0 kPa	2.100	.40
0.300	D.G.S. (thawed)	97.2	63.66	94.8	52.93	10.0 kPa	2.100	.40
0.300	D.G.S. (thawed)	103.7	178.77	98.3	121.08	6.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	118.1	464.47	109.9	273.60	6.0 kPa	1.970	.40
0.324	D.G.S.	132.8	1102.40	122.4	604.58	6.0 kPa	1.970	.40
1.524	Subgrade	130.3	185.12	128.0	175.81	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

12 February 1979 (Day 43)

	Plate Pressure (kPa):	264		554				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	14382.0	--	14382.0	--	-7.7°	2.320	.30
0.250	D.G.S. (frozen)	32664.0	--	32664.0	--	-6.5°	1.800	.30
0.300	D.G.S. (frozen)	12543.0	--	12543.0	--	-2.0°	1.800	.30
0.300	D.G.S. (frozen)	3395.0	--	3395.0	--	-0.4°	1.800	.30
0.300	D.G.S. (frozen)	1101.0	--	1101.0	--	-0.1°	1.800	.30
0.324	D.G.S.	159.2	4190.89	145.8	2192.83	6.0 kPa	1.970	.40
1.524	Subgrade	130.4	185.71	129.9	183.56	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

7 March 1979 (Day 66)

	Plate Pressure (kPa):	268		572				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	7589.0	--	7589.0	--	4.5°	2.320	.40
0.250	D.G.S. (thawed)	89.0	127.95	95.8	219.58	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	83.0	76.47	82.8	75.25	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	92.8	174.72	89.0	127.67	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	105.6	449.43	99.0	280.26	0.0 kPa	1.970	.45
0.324	D.G.S.	129.7	926.27	119.6	510.45	6.0 kPa	1.970	.40
1.524	Subgrade	131.1	188.31	127.9	175.43	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

12 March 1979 (Day 71)

	Plate Pressure (kPa):	274		578				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	7251.0	--	7251.0	--	5.2°	2.320	.40
0.250	D.G.S. (thawed)	89.1	129.48	95.9	220.91	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	82.9	75.84	82.7	74.81	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	92.7	172.32	88.9	126.88	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	105.3	442.10	98.9	278.31	0.0 kPa	1.970	.45
0.324	D.G.S.	129.4	909.56	119.5	506.27	6.0 kPa	1.970	.40
1.524	Subgrade	131.0	188.13	128.9	179.69	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

20 March 1979 (Day 79)

	Plate Pressure (kPa):	261		560				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	2054.0	--	2054.0	--	20.8°	2.320	.50
0.250	D.G.S. (thawed)	87.9	117.24	94.7	201.94	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	81.5	67.05	81.1	64.37	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	92.2	165.65	88.3	120.58	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	105.3	440.59	98.7	273.53	0.0 kPa	1.970	.45
0.324	D.G.S.	129.7	925.81	119.5	506.92	6.0 kPa	1.970	.40
1.524	Subgrade	131.1	188.39	129.0	179.84	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

27 March 1979 (Day 86)

	Plate Pressure (kPa):	261		547				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	3997.0	--	3997.0	--	13.3°	2.320	.45
0.250	D.G.S. (thawed)	91.5	71.19	94.4	112.39	6.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	82.7	74.45	82.4	72.72	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	92.9	175.21	89.0	128.18	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	105.8	456.78	99.3	286.40	0.0 kPa	1.970	.45
0.324	D.G.S.	130.1	948.92	120.1	527.95	6.0 kPa	1.970	.40
1.524	Subgrade	131.2	188.60	129.2	180.11	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

3 April 1979 (Day 93)

	Plate Pressure (kPa):	249		553				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5777.0	--	5777.0	--	8.5°	2.320	.45
0.250	D.G.S. (thawed)	98.0	67.71	104.5	108.58	10.0 kPa	2.100	.40
0.300	D.G.S. (thawed)	83.9	82.84	83.7	81.45	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	95.0	206.15	91.0	151.46	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	126.2	434.00	116.9	247.49	10.0 kPa	2.100	.40
0.324	D.G.S.	142.4	1058.80	130.5	556.29	10.0 kPa	2.100	.40
1.524	Subgrade	132.7	195.13	130.7	186.63	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

23 April 1979 (Day 113)

	Plate Pressure (kPa):	253		554				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	782.0	--	782.0	--	30.0°	2.320	.50
0.250	D.G.S. (thawed)	90.8	67.31	96.9	108.43	6.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	87.2	49.81	84.5	39.78	6.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	94.0	190.69	90.4	143.87	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	125.1	408.40	116.2	236.72	10.0 kPa	2.100	.40
0.324	D.G.S.	141.5	1010.43	129.9	536.97	10.0 kPa	2.100	.40
1.524	Subgrade	132.3	193.42	130.3	185.05	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

7 May 1979 (Day 127)

	Plate Pressure (kPa):	264		554				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	421.0	--	421.0	--	35.2°	2.320	.50
0.250	D.G.S. (thawed)	95.5	56.04	101.5	87.54	10.0 kPa	2.100	.40
0.300	D.G.S. (thawed)	82.1	70.62	82.0	70.09	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	93.6	184.96	90.2	141.73	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	124.5	393.72	116.1	235.12	10.0 kPa	2.100	.40
0.324	D.G.S.	140.8	972.02	129.8	534.59	10.0 kPa	2.100	.40
1.524	Subgrade	132.6	194.48	130.6	186.17	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

29 May 1979 (Day 149)

	Plate Pressure (kPa):	259		563				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	550.0	--	550.0	--	33.0°	2.320	.50
0.250	D.G.S. (thawed)	90.6	66.91	96.7	107.23	6.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	85.9	51.16	83.7	42.52	5.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	98.5	182.73	94.8	137.63	3.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	124.8	400.18	116.0	233.67	10.0 kPa	2.100	.40
0.324	D.G.S.	141.1	990.11	129.6	529.66	10.0 kPa	2.100	.40
1.524	Subgrade	132.3	193.26	130.2	184.85	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

24 July 1979 (Day 206)

	Plate Pressure (kPa):	274		582				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	201.0	--	201.0	--	40.9°	2.320	.50
0.250	D.G.S. (thawed)	97.5	65.43	104.2	106.57	10.0 kPa	2.100	.40
0.300	D.G.S. (thawed)	87.7	52.10	85.7	43.99	6.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	100.2	182.02	96.6	139.03	4.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	124.5	393.29	116.0	234.24	10.0 kPa	2.100	.40
0.324	D.G.S.	140.6	962.30	129.5	525.21	10.0 kPa	2.100	.40
1.524	Subgrade	132.6	194.45	130.5	185.94	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

27 September 1979 (Day 270)

	Plate Pressure (kPa):	276		597				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	736.0	--	736.0	--	30.5°	2.320	.50
0.250	D.G.S. (thawed)	97.6	65.98	103.9	104.32	10.0 kPa	2.100	.40
0.300	D.G.S. (thawed)	86.4	53.62	84.4	44.99	5.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	100.3	183.07	96.6	138.51	4.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	124.6	395.48	115.9	233.43	10.0 kPa	2.100	.40
0.324	D.G.S.	140.7	966.33	129.4	522.76	10.0 kPa	2.100	.40
1.524	Subgrade	132.6	194.44	130.4	185.80	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

19 November 1979 (Day 323)

	Plate Pressure (kPa):	274		597				
Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or φ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5610.0	--	5612.0	--	8.9°	2.320	.45
0.250	D.G.S. (thawed)	99.9	78.23	106.6	125.49	10.0 kPa	2.100	.40
0.300	D.G.S. (thawed)	88.3	62.63	86.6	54.27	5.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	101.2	196.06	97.2	145.69	4.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	125.4	415.75	116.6	242.65	10.0 kPa	2.100	.40
0.324	D.G.S.	141.4	1003.94	129.9	538.98	10.0 kPa	2.100	.40
1.524	Subgrade	132.6	194.62	130.5	186.06	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

* Notes:

(1) Moduli, stresses, and strains calculated by NELAPAV

(2) M_r = resilient modulus, J_1 = first stress invariant or bulk stress, J_2 = second stress invariant, ϕ = moisture tension, γ_d = dry unit weight, μ_r = resilient Poisson's ratio

(3) M_r and J_1 are calculated at r=0 and center of respective layer

(4) D.G.S. refers to dense-graded stone

(5) τ_{oct} = octahedral shear stress (kPa)

(6) Negative normal stresses and strains are compressive

Tangential Strain ϵ_t (r = 0, z = .05) and Vertical Strain ϵ_v (r = 0, z = 1.524)

	31 Oct	12 Feb	7 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	7 May	29 May	24 Jul	27 Sept	19 Nov
ϵ_t (low pressure):	2.082×10^{-4}	-1.880×10^{-6}	2.126×10^{-4}	3.578×10^{-4}	2.220×10^{-4}	2.705×10^{-4}	2.113×10^{-4}	4.153×10^{-4}	4.343×10^{-4}	4.414×10^{-4}	4.323×10^{-4}	4.287×10^{-4}	2.31710^{-4}
(high pressure):	4.292×10^{-4}	-3.888×10^{-6}	4.410×10^{-4}	7.327×10^{-4}	4.556×10^{-4}	5.409×10^{-4}	4.558×10^{-4}	8.590×10^{-4}	8.547×10^{-4}	9.006×10^{-4}	8.457×10^{-4}	8.73×10^{-4}	4.911×10^{-4}
ϵ_v (low pressure):	-1.978×10^{-4}	-1.583×10^{-4}	-2.042×10^{-4}	-2.039×10^{-4}	-2.052×10^{-4}	-2.028×10^{-4}	-2.023×10^{-4}	-2.025×10^{-4}	-2.065×10^{-4}	-2.036×10^{-4}	-2.073×10^{-4}	-2.071×10^{-4}	-2.052×10^{-4}
(high pressure):	-2.427×10^{-4}	-1.675×10^{-4}	-2.557×10^{-4}	-2.583×10^{-4}	-2.594×10^{-4}	-2.536×10^{-4}	-2.538×10^{-4}	-2.548×10^{-4}	-2.581×10^{-4}	-2.565×10^{-4}	-2.612×10^{-4}	-2.619×10^{-4}	-2.583×10^{-4}

Table D5b. Resilient moduli and supporting data calculated by NELAPAV for dense-graded stone test section, 1980.

25 February 1980 (Day 56)

Plate Pressure (kPa): 278 / 569

Thickness (m)	Materials	M_r (MPa) [278]	J_2/τ_{oct} (kPa) [278]	M_r (MPa) [569]	J_2/τ_{oct} (kPa) [569]	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5372.0	--	5372.0	--	11.3°	2.320	.45
0.250	D.G.S. (thawed)	101.6	246.13	110.9	611.57	0.0 kPa	1.970	.45
0.300	D.G.S. (frozen)	1934.0	--	1934.3	--	-0.2°	1.800	.30
0.250	D.G.S. (frozen)	1101.0	--	1101.0	--	-0.1°	1.800	.30
0.100	D.G.S. (frozen)	1101.0	--	1101.0	--	-0.1°	1.800	.30
0.574	D.G.S.	145.6	1224.90	134.7	704.44	10.0 kPa	2.100	.40
1.524	Subgrade	130.8	186.99	131.0	188.07	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

12 March 1980 (Day 72)

Plate Pressure (kPa): 240 / 525

Thickness (m)	Materials	M_r (MPa) [240]	J_2/τ_{oct} (kPa) [240]	M_r (MPa) [525]	J_2/τ_{oct} (kPa) [525]	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	4819.0	--	4819.0	--	12.7°	2.320	.45
0.250	D.G.S. (thawed)	89.5	132.91	97.4	249.11	0.0 kPa	1.800	.45
0.300	D.G.S. (thawed)	90.5	144.98	94.8	203.80	0.0 kPa	1.800	.45
0.250	D.G.S. (frozen)	1101.0	--	1101.0	--	-0.1°	1.800	.30
0.100	D.G.S. (thawed)	107.5	513.53	102.9	372.36	0.0 kPa	1.800	.45
0.574	D.G.S.	137.6	821.27	127.3	463.59	10.0 kPa	2.100	.40
1.524	Subgrade	130.6	186.41	128.9	179.45	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

19 March 1980 (Day 79)

Plate Pressure (kPa): 369 / 525

Thickness (m)	Materials	M_r (MPa) [369]	J_2/τ_{oct} (kPa) [369]	M_r (MPa) [525]	J_2/τ_{oct} (kPa) [525]	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	2651.0	--	2651.0	--	20.8°	2.320	.50
0.250	D.G.S. (thawed)	93.4	182.82	96.7	235.14	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	81.6	67.48	81.9	69.72	0.0 kPa	1.970	.45
0.250	D.G.S. (frozen)	1934.0	--	1934.0	--	-0.2°	1.800	.30
0.100	D.G.S. (frozen)	1101.0	--	1101.0	--	-0.1°	1.800	.30
0.574	D.G.S.	137.0	795.37	132.7	628.52	10.0 kPa	2.100	.40
1.524	Subgrade	131.7	190.76	131.1	188.32	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

22 March 1980 (Day 82)

Plate Pressure (kPa): 201 / 449

Thickness (m)	Materials	M_r (MPa) [201]	J_2/τ_{oct} (kPa) [201]	M_r (MPa) [449]	J_2/τ_{oct} (kPa) [449]	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	8958.0	--	8958.0	--	4.4°	2.320	.40
0.250	D.G.S. (thawed)	87.6	114.31	95.4	213.25	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	88.5	72.83	86.8	63.05	4.0 kPa	1.970	.40
0.250	D.G.S. (thawed)	112.1	182.68	105.2	114.19	10.0 kPa	2.100	.40
0.100	D.G.S. (thawed)	122.6	350.88	113.2	195.14	10.0 kPa	2.100	.40
0.574	D.G.S.	140.6	963.78	127.2	462.28	10.0 kPa	2.100	.40
1.524	Subgrade	133.3	197.50	131.3	189.27	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

26 March 1980 (Day 86)

Plate Pressure (kPa): 232 / 465

Thickness (m)	Materials	M_r (MPa) [232]	J_2/τ_{oct} (kPa) [232]	M_r (MPa) [465]	J_2/τ_{oct} (kPa) [465]	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	4812.0	--	4812.0	--	11.3°	2.320	.45
0.250	D.G.S. (thawed)	90.6	76.07	96.1	117.11	5.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	89.4	68.82	88.0	63.39	5.0 kPa	1.970	.40
0.250	D.G.S. (thawed)	110.8	145.45	104.7	95.67	11.0 kPa	2.100	.35
0.100	D.G.S. (thawed)	120.5	309.19	113.2	195.34	10.0 kPa	2.200	.40
0.574	D.G.S.	128.4	495.01	119.1	494.62	6.0 kPa	1.970	.40
1.524	Subgrade	132.2	192.89	130.7	186.67	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

29 March 1980 (Day 89)

Plate Pressure (kPa): 255 / 470

Thickness (m)	Materials	M_r (MPa) [255]	J_2/τ_{oct} (kPa) [255]	M_r (MPa) [470]	J_2/τ_{oct} (kPa) [470]	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5310.0	--	5310.0	--	11.4°	2.320	.45
0.250	D.G.S. (thawed)	91.4	81.08	96.3	119.22	5.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	89.4	68.49	88.3	62.93	5.0 kPa	1.970	.40
0.250	D.G.S. (thawed)	112.1	136.39	106.6	94.43	12.0 kPa	2.100	.35
0.100	D.G.S. (thawed)	119.4	290.23	113.1	194.88	10.0 kPa	2.100	.40
0.574	D.G.S.	127.1	798.47	119.0	492.01	6.0 kPa	1.970	.40
1.524	Subgrade	132.0	192.22	130.7	186.55	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

3 April 1980 (Day 94)

Plate Pressure (kPa): 259 / 484

Thickness (m)	Materials	M_r (MPa) [259]	J_2/τ_{oct} (kPa) [259]	M_r (MPa) [484]	J_2/τ_{oct} (kPa) [484]	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	1415.0	--	1415.0	--	29.1°	2.320	.50
0.250	D.G.S. (thawed)	90.0	72.08	94.9	106.30	5.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	87.8	60.20	86.5	53.81	5.0 kPa	1.970	.40
0.250	D.G.S. (thawed)	108.8	126.95	103.4	87.13	11.0 kPa	2.100	.35
0.100	D.G.S. (thawed)	110.7	289.90	105.1	197.31	6.0 kPa	1.970	.40
0.574	D.G.S.	126.3	762.71	118.1	466.47	6.0 kPa	1.970	.40
1.524	Subgrade	131.9	191.44	130.4	185.54	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

10 April 1980 (Day 101)

Plate Pressure (kPa): 241 / 491

Thickness (m)	Materials	M_r (MPa) [241]	J_2/τ_{oct} (kPa) [241]	M_r (MPa) [491]	J_2/τ_{oct} (kPa) [491]	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	4573.0	--	4573.0	--	13.4°	2.320	.45
0.250	D.G.S. (thawed)	98.5	270.44	104.2	407.49	0.0 kPa	1.970	.45
0.300	D.G.S. (thawed)	88.8	65.31	86.8	55.55	5.0 kPa	1.970	.40
0.250	D.G.S. (thawed)	106.3	152.61	100.6	101.47	8.5 kPa	1.970	.40
0.100	D.G.S. (thawed)	102.0	196.96	96.4	104.29	6.0 kPa	1.970	.40
0.574	D.G.S.	116.0	406.53	107.7	236.49	6.0 kPa	1.970	.40
1.524	Subgrade	131.9	191.78	130.2	184.88	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

17 April 1980 (Day 108)

Plate Pressure (kPa): 239 / 451

Thickness (m)	Materials	M_r (MPa) [239]	J_2/τ_{oct} (kPa) [239]	M_r (MPa) [451]	J_2/τ_{oct} (kPa) [451]	T(°C) or ψ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	1798.0	--	1798.0	--	25.9°	2.320	.50
0.250	D.G.S. (thawed)	91.0	68.21	95.8	99.89	6.0 kPa	1.970	.40
0.300	D.G.S. (thawed)	87.5	58.90	86.0	51.67	5.0 kPa	1.970	.40
0.250	D.G.S. (thawed)	108.3	141.23	103.2	98.87	10.0 kPa	2.100	.40
0.100*	D.G.S. (thawed)	101.6	338.57	95.5	215.02	0.0 kPa	1.970	.45
0.574	D.G.S.	115.6	875.31	101.6	338.35	0.0 kPa	1.970	.45
1.524	Subgrade	131.9	191.46	130.5	185.79	--	1.055	.35
∞	Subgrade	200.0	--	200.0	--	--	1.055	.35

* Notes: (1) Moduli, stresses, and strains calculated by NELAPAV

(2) M_r = resilient modulus, J_1 = first stress invariant or bulk stress, J_2 = second stress invariant, ψ = moisture tension, γ_d = dry unit weight, μ_r = resilient Poisson's ratio

(3) M_r and J_1 are calculated at r=0 and center of respective layer

(4) D.G.S. refers to dense-graded stone

(5) τ_{oct} = octahedral shear stress (kPa)

(6) Negative normal stresses and strains are compressive

Tangential Strain ϵ_t (r = 0, z = .05) and Vertical Strain ϵ_v (r = 0, z = 1.524)

	25 Feb	12 Mar	19 Mar	22 Mar	26 Mar	29 Mar	3 Apr	10 Apr	17 Apr
ϵ_t(low pressure):	2.085×10^{-4}	2.263×10^{-4}	4.306×10^{-4}	1.433×10^{-4}	2.183×10^{-4}	2.282×10^{-4}	3.806×10^{-4}	2.233×10^{-4}	3.256×10^{-4}
(high pressure):	4.092×10^{-4}	4.748×10^{-4}	5.888×10^{-4}	3.461×10^{-4}	4.253×10^{-4}	4.112×10^{-4}	6.853×10^{-4}	4.433×10^{-4}	5.942×10^{-4}
ϵ_v(low pressure):	-1.771×10^{-4}	-1.904×10^{-4}	-1.995×10^{-4}	-1.922×10^{-4}	-1.943×10^{-4}	-1.978×10^{-4}	-1.988×10^{-4}	-1.973×10^{-4}	-1.977×10^{-4}
(high pressure):	-2.008×10^{-4}	-2.323×10^{-4}	-2.150×10^{-4}	-2.392×10^{-4}	-2.307×10^{-4}	-2.313×10^{-4}	-2.348×10^{-4}	-2.384×10^{-4}	-2.335×10^{-4}

Table D6a. Resilient moduli and supporting data calculated by NELAPAV for Sibley till test section, 1979.

30 October 1978 (Day -63)

Plate Pressure (kPa): ______ ; 472.2

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	—	—	4261.0	—	12.5°	2.320	.45
0.250	S.T. (thawed)	—	—	51.5	72.94	12.0 kPa	1.850	.35
0.300	S.T. (thawed)	—	—	47.2	46.63	12.0 kPa	1.850	.35
0.300	S.T. (thawed)	—	—	55.8	110.89	12.0 kPa	1.850	.35
0.624	S.T.	—	—	70.9	387.20	12.0 kPa	1.850	.35
1.524	Subgrade	—	—	126.0	168.12	—	1.055	.35
∞	Subgrade	—	—	200.0	—	—	1.055	.35

12 February 1979 (Day 43)

Plate Pressure (kPa): 271.0 ; 566.6

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	7984.0	--	7984.0	--	3.7°	2.320	.35
0.250	S.T. (frozen)	8046.0	--	8046.0	--	-2.6°	1.890	.35
0.300	S.T. (frozen)	12274.0	--	12274.0	--	-5.0°	1.890	.35
0.300	S.T. (frozen)	7641.0	--	7641.0	--	-2.4°	1.890	.35
0.624	S.T. (frozen)	3211.0	—	3211.0	--	-0.6°	1.890	.35
1.524	Subgrade	131.4	189.69	131.0	188.03	—	1.055	.35
∞	Subgrade	200.0	—	200.0	--	—	1.055	.35

6 March 1979 (Day 65)

Plate Pressure (kPa): 255.9 ; 529.7

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5819.0	--	5819.0	--	8.4°	2.320	.45
0.250	S.T. (thawed)	39.8	123.37	39.8	199.36	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	37.1	84.63	37.0	84.20	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	43.1	185.52	40.8	140.39	0.0 kPa	1.900	.45
0.624	S.T. (thawed)	55.5	689.91	50.6	428.07	0.0 kPa	1.900	.45
1.524	Subgrade	129.2	169.04	125.3	165.74	--	1.055	.35
∞	Subgrade	200.0	—	200.0	--	--	1.055	.35

12 March 1979 (Day 71)

Plate Pressure (kPa): 268.3 ; 532.4

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	4982.0	--	4982.0	—	10.5°	2.320	.45
0.250	S.T. (thawed)	40.1	128.20	43.9	203.73	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	37.1	85.38	37.3	87.60	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	43.6	196.89	41.8	159.22	0.0 kPa	1.900	.45
0.624	S.T. (thawed)	67.6	576.48	61.7	358.02	8.0 kPa	1.850	.40
1.524	Subgrade	128.8	179.10	126.1	168.59	—	1.055	.35
∞	Subgrade	200.0	--	200.0	—	—	1.055	.35

20 March 1979 (Day 79)

Plate Pressure (kPa): 264.2 ; 544.7

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	1996.0	—	1996.0	—	21.1°	2.320	.50
0.250	S.T. (thawed)	42.4	80.87	46.1	146.56	5.0 kPa	1.850	.40
0.300	S.T. (thawed)	40.4	62.95	39.9	68.37	5.0 kPa	1.850	.40
0.300	S.T. (thawed)	52.2	150.35	49.2	110.10	8.0 kPa	1.850	.40
0.624	S.T. (thawed)	67.9	590.74	61.7	357.70	8.0 kPa	1.850	.40
1.524	Subgrade	128.4	177.64	125.7	167.12	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

27 March 1979 (Day 86)

Plate Pressure (kPa): 246.4 ; 547.5

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5903.0	—	5903.0	—	8.2°	2.320	.45
0.250	S.T. (thawed)	43.9	83.13	48.2	134.93	6.0 kPa	1.850	.40
0.300	S.T. (thawed)	42.0	76.84	41.6	73.68	5.0 kPa	1.850	.40
0.300	S.T. (thawed)	55.7	153.19	51.6	102.08	10.0 kPa	1.850	.35
0.624	S.T. (thawed)	72.9	618.73	65.1	344.13	10.0 kPa	1.850	.35
1.524	Subgrade	128.8	179.13	126.1	168.83	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

3 April 1979 (Day 93)

Plate Pressure (kPa): 255.9 ; 562.5

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5988.0	—	5988.0	—	8.0°	2.320	.45
0.250	S.T. (thawed)	46.4	107.99	50.9	130.97	8.0 kPa	1.850	.40
0.300	S.T. (thawed)	42.2	78.53	42.0	77.13	5.0 kPa	1.850	.40
0.300	S.T. (thawed)	59.0	149.42	54.7	100.70	12.0 kPa	1.850	.35
0.624	S.T. (thawed)	77.0	596.03	68.9	334.99	12.0 kPa	1.850	.35
1.524	Subgrade	128.7	180.23	126.6	170.46	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

23 April 1979 (Day 113)

Plate Pressure (kPa): 258.7 ; 539.5

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	2596.0	—	2596.0	—	18.3°	2.320	.50
0.250	S.T. (thawed)	46.5	82.18	50.7	128.27	8.0 kPa	1.850	.40
0.300	S.T. (thawed)	44.8	67.24	44.3	63.59	8.0 kPa	1.850	.40
0.300	S.T. (thawed)	58.3	139.37	54.3	96.20	12.0 kPa	1.850	.35
0.624	S.T. (thawed)	76.5	576.47	69.0	336.47	12.0 kPa	1.850	.35
1.524	Subgrade	127.5	174.01	126.7	170.86	—	1.055	.35
∞	Subgrade	200.0	—	200.0	--	—	1.055	.35

8 May 1979 (Day 128)

Plate Pressure (kPa): 271.0 ; 559.8

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	2502.0	--	2502.0	--	18.7°	2.320	.50
0.250	S.T. (thawed)	47.7	49.34	50.7	67.48	12.0 kPa	1.850	.35
0.300	S.T. (thawed)	45.2	51.19	43.4	41.58	10.0 kPa	1.850	.35
0.300	S.T. (thawed)	55.2	146.28	51.7	103.37	10.0 kPa	1.850	.35
0.624	S.T. (thawed)	76.5	575.14	69.1	338.41	12.0 kPa	1.850	.35
1.524	Subgrade	128.3	176.96	126.7	170.96	--	1.055	.35
∞	Subgrade	200.0	--	200.0	—	—	1.055	.35

30 May 1979 (Day 150)

Plate Pressure (kPa): 261.4 ; 566.6

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	3269.0	—	3269.0	—	15.7°	2.320	.45
0.250	S.T. (thawed)	44.6	77.26	48.9	124.34	7.0 kPa	1.850	.40
0.300	S.T. (thawed)	41.5	84.27	41.8	87.94	4.0 kPa	1.900	.45
0.300	S.T. (thawed)	49.8	160.17	47.0	118.05	6.0 kPa	1.850	.40
0.624	S.T. (thawed)	71.3	552.91	64.0	316.02	10.0 kPa	1.850	.35
1.524	Subgrade	128.5	178.11	126.6	170.47	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	--	1.055	.35

24 July 1979 (Day 206)

Plate Pressure (kPa): 280.6 ; 589.9

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	1349.0	—	1349.0	—	25.0°	2.320	.50
0.250	S.T. (thawed)	49.1	34.71	51.6	44.96	15.0 kPa	1.850	.35
0.300	S.T. (thawed)	41.6	62.51	41.2	59.89	6.0 kPa	1.850	.40
0.300	S.T. (thawed)	52.9	161.16	50.3	124.08	8.0 kPa	1.850	.40
0.624	S.T. (thawed)	82.6	519.50	74.5	302.79	15.0 kPa	1.850	.35
1.524	Subgrade	128.5	177.81	126.2	169.21	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

27 September 1979 (Day 270)

Plate Pressure (kPa): 283.3 ; 596.8

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5988.0	—	5988.0	—	8.0°	2.320	.45
0.250	S.T. (thawed)	43.4	91.29	47.0	146.14	5.0 kPa	1.850	.40
0.300	S.T. (thawed)	41.6	72.89	41.4	71.57	5.0 kPa	1.850	.40
0.300	S.T. (thawed)	52.1	172.94	49.5	133.65	7.0 kPa	1.850	.40
0.624	S.T. (thawed)	82.8	525.37	74.7	306.98	15.0 kPa	1.850	.40
1.524	Subgrade	128.4	177.71	126.2	169.10	—	1.055	.35
∞	Subgrade	200.0	—	200.0	—	—	1.055	.35

19 November 1979 (Day 323)

Plate Pressure (kPa): 273.7 ; 589.9

Thickness (m)	Materials	M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	6876.0	—	6876.0	--	6.0°	2.320	.40
0.250	S.T. (thawed)	46.7	60.95	50.5	91.32	10.0 kPa	1.850	.35
0.300	S.T. (thawed)	47.0	63.40	46.0	56.41	10.0 kPa	1.850	.35
0.300	S.T. (thawed)	65.1	150.74	60.7	103.90	15.0 kPa	1.850	.35
0.624	S.T. (thawed)	84.3	577.71	75.7	329.82	15.0 kPa	1.850	.35
1.524	Subgrade	128.7	178.67	126.6	170.43	--	1.055	.35
∞	Subgrade	200.0	—	200.0	--	--	1.055	.35

Tangential Strain ϵ_t (r = 0, z = .05) and Vertical Strain ϵ_v (r = 0, z = 1.524)

	30 Oct	12 Feb	6 Mar	12 Mar	20 Mar	27 Mar	3 Apr	23 Apr	8 May	30 May	24 Jul	27 Sep	19 Nov
ϵ_t(low pressure):	--	1.733×10^{-6}	3.267×10^{-4}	3.737×10^{-4}	5.567×10^{-4}	2.971×10^{-4}	3.001×10^{-4}	4.582×10^{-4}	4.769×10^{-4}	4.350×10^{-4}	6.291×10^{-4}	3.406×10^{-4}	2.944×10^{-4}
(high pressure):	6.333×10^{-4}	3.700×10^{-6}	6.586×10^{-4}	7.214×10^{-4}	1.104×10^{-3}	6.419×10^{-4}	6.412×10^{-4}	9.205×10^{-4}	9.603×10^{-4}	9.065×10^{-4}	1.285×10^{-3}	[illegible]	6.307×10^{-4}
ϵ_v(low pressure):	--	-1.593×10^{-4}	-2.082×10^{-4}	-2.078×10^{-4}	-2.030×10^{-4}	-1.951×10^{-4}	-1.967×10^{-4}	-1.968×10^{-4}	-1.982×10^{-4}	-2.007×10^{-4}	-2.031×10^{-4}	-2.032×10^{-4}	-1.980×10^{-4}
(high pressure):	-2.309×10^{-4}	-1.669×10^{-4}	-2.648×10^{-4}	-2.620×10^{-4}	-2.597×10^{-4}	-2.483×10^{-4}	-2.513×10^{-4}	-2.448×10^{-4}	-2.495×10^{-4}	-2.589×10^{-4}	-2.612×10^{-4}	-2.610×10^{-4}	-2.524×10^{-4}

Table D6b. Resilient moduli and supporting data calculated by NELAPAV for Sibley till test section, 1980.

25 February 1980 (Day 56)

Thickness (m)	Materials	Plate Pressure (kPa): 300.0 M_r (MPa)	J_2/τ_{oct} (kPa)	Plate Pressure (kPa): 575.0 M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	9798.0	—	9798.0	—	3.2°	2.320	.40
0.250	S.T. (frozen)	3449.0	—	3449.0	—	-0.7°	1.890	.35
0.300	S.T. (frozen)	2775.0	—	2775.0	—	-0.5°	1.890	.35
0.300	S.T. (frozen)	3122.0	—	3122.0	—	-0.6°	1.890	.35
0.624	S.T. (frozen)	591.0	—	591.0	—	0.0°	1.890	.35
1.524	Subgrade	131.0	187.85	129.3	181.05	—	1.055	.35
*	Subgrade	200.0	—	200.0	—	—	1.055	.35

12 March 1980 (Day 72)

Thickness (m)	Materials	Plate Pressure (kPa): 273.0 M_r (MPa)	J_2/τ_{oct} (kPa)	Plate Pressure (kPa): 600.0 M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	4058.0	—	4058.0	—	15.0°	2.320	.45
0.250	S.T. (thawed)	40.2	128.51	44.6	220.61	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	37.9	82.58	38.2	85.00	1.0 kPa	1.900	.45
0.300	S.T. (thawed)	45.5	183.57	43.3	141.20	2.0 kPa	1.900	.45
0.624	S.T. (thawed)	62.1	591.77	56.0	345.82	5.0 kPa	1.850	.40
1.524	Subgrade	128.4	177.54	125.8	167.52	—	1.055	.35
*	Subgrade	200.0	—	200.0	—	—	1.055	.35

19 March 1980 (Day 79)

Thickness (m)	Materials	Plate Pressure (kPa): 254.0 M_r (MPa)	J_2/τ_{oct} (kPa)	Plate Pressure (kPa): 360.0 M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	2217.0	—	2217.0	—	20.0°	2.320	.50
0.250	S.T. (thawed)	39.4	115.96	41.1	145.00	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	36.3	75.44	36.1	73.73	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	42.8	178.56	41.6	153.91	0.0 kPa	1.900	.45
0.624	S.T. (thawed)	58.4	673.64	55.7	526.25	2.0 kPa	1.900	.45
1.524	Subgrade	128.8	178.97	128.3	177.00	—	1.055	.35
*	Subgrade	200.0	—	200.0	—	—	1.055	.35

22 March 1980 (Day 82)

Thickness (m)	Materials	Plate Pressure (kPa): 167.0 M_r (MPa)	J_2/τ_{oct} (kPa)	Plate Pressure (kPa): 330.0 M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5988.0	—	5988.0	—	8.0°	2.320	.40
0.250	S.T. (thawed)	37.9	95.18	40.9	141.37	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	37.6	91.30	36.9	82.79	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	45.2	237.70	42.2	167.22	0.0 kPa	1.900	.45
0.624	S.T. (thawed)	59.4	984.36	53.8	588.72	0.0 kPa	1.900	.45
1.524	Subgrade	130.2	184.56	128.6	178.51	—	1.055	.35
*	Subgrade	200.0	—	200.0	—	—	1.055	.35

26 March 1980 (Day 86)

Thickness (m)	Materials	Plate Pressure (kPa): 246.0 M_r (MPa)	J_2/τ_{oct} (kPa)	M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	4891.0	—	—	—	12.5°	2.320	.45
0.250	S.T. (thawed)	39.5	117.33	—	—	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	36.9	83.02	—	—	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	43.2	188.84	—	—	0.0 kPa	1.900	.45
0.624	S.T. (thawed)	55.9	721.60	—	—	0.0 kPa	1.900	.45
1.524	Subgrade	129.4	181.42	—	—	—	1.055	.35
*	Subgrade	200.0	—	—	—	—	1.055	.35

29 March 1980 (Day 89)

Thickness (m)	Materials	Plate Pressure (kPa): 258.0 M_r (MPa)	J_2/τ_{oct} (kPa)	Plate Pressure (kPa): 505.0 M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5471.0	—	5471.0	—	11.0°	2.320	.45
0.250	S.T. (thawed)	39.7	121.22	43.2	188.08	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	37.0	84.22	36.9	88.23	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	43.2	188.01	41.1	144.84	0.0 kPa	1.900	.45
0.624	S.T. (thawed)	57.1	695.58	52.4	443.71	1.0 kPa	1.900	.45
1.524	Subgrade	129.3	181.01	127.7	174.75	—	1.055	.35
*	Subgrade	200.0	—	200.0	—	—	1.055	.35

3 April 1980 (Day 94)

Thickness (m)	Materials	Plate Pressure (kPa): 265.0 M_r (MPa)	J_2/τ_{oct} (kPa)	Plate Pressure (kPa): 516.0 M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	3823.0	—	3823.0	—	15.8°	2.320	.50
0.250	S.T. (thawed)	40.7	119.70	44.3	185.79	1.0 kPa	1.900	.45
0.300	S.T. (thawed)	36.8	81.08	36.8	80.94	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	44.0	179.21	41.9	139.19	1.0 kPa	1.900	.45
0.624	S.T. (thawed)	58.3	667.08	53.5	428.67	2.0 kPa	1.900	.45
1.524	Subgrade	129.2	180.62	125.5	166.50	—	1.055	.35
*	Subgrade	200.0	—	200.0	—	—	1.055	.35

10 April 1980 (Day 101)

Thickness (m)	Materials	Plate Pressure (kPa): 248.0 M_r (MPa)	J_2/τ_{oct} (kPa)	Plate Pressure (kPa): 504.0 M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	6876.0	—	6876.0	—	16.0°	2.320	.40
0.250	S.T. (thawed)	39.6	119.00	43.2	188.39	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	37.3	86.96	37.1	85.55	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	43.5	195.55	41.2	147.41	0.0 kPa	1.900	.45
0.624	S.T. (thawed)	57.6	723.76	52.5	448.52	1.0 kPa	1.900	.45
1.524	Subgrade	129.4	181.45	125.7	167.32	—	1.055	.35
*	Subgrade	200.0	—	200.0	—	—	1.055	.35

17 April 1980 (Day 108)

Thickness (m)	Materials	Plate Pressure (kPa): 240.0 M_r (MPa)	J_2/τ_{oct} (kPa)	Plate Pressure (kPa): 455.0 M_r (MPa)	J_2/τ_{oct} (kPa)	T(°C) or ϕ (kPa)	γ_d (Mg/m³)	μ_r
0.050	Asphalt Concrete	5988.0	—	5988.0	—	8.0°	2.320	.45
0.250	S.T. (thawed)	42.3	68.71	45.3	97.55	6.0 kPa	1.850	.40
0.300	S.T. (thawed)	37.3	87.69	37.2	85.67	0.0 kPa	1.900	.45
0.300	S.T. (thawed)	43.8	201.77	41.6	154.91	0.0 kPa	1.900	.45
0.624	S.T. (thawed)	59.5	742.63	54.7	476.65	2.0 kPa	1.900	.45
1.524	Subgrade	128.9	179.48	127.5	174.20	—	1.055	.35
*	Subgrade	200.0	—	200.0	—	—	1.055	.35

Tangential Strain ϵ_t (r = 0, z = .05) and Vertical Strain ϵ_v (r = 0, z = 1.524)

	25 Feb	12 Mar	19 Mar	22 Mar	26 Mar	29 Mar	3 Apr	10 Apr	17 Apr
ϵ_t (low pressure):	8.156×10^{-6}	4.214×10^{-4}	5.321×10^{-4}	2.151×10^{-4}	3.444×10^{-4}	3.373×10^{-4}	4.222×10^{-4}	2.906×10^{-4}	2.913×10^{-4}
(high pressure):	1.568×10^{-5}	8.937×10^{-4}	7.411×10^{-4}	4.171×10^{-4}	--	6.445×10^{-4}	7.984×10^{-4}	5.771×10^{-4}	5.416×10^{-4}
ϵ_v (low pressure):	-1.668×10^{-4}	-2.064×10^{-4}	-2.072×10^{-4}	-1.878×10^{-4}	-2.046×10^{-4}	-2.069×10^{-4}	-2.090×10^{-4}	-2.044×10^{-4}	-2.012×10^{-4}
(high pressure):	-1.792×10^{-4}	-2.172×10^{-4}	-2.304×10^{-4}	-2.217×10^{-4}	--	-2.588×10^{-4}	-2.599×10^{-4}	-2.553×10^{-4}	-2.454×10^{-4}

* Notes: (1) Moduli, stresses, and strains calculated by NELAPAV

(2) M_r = resilient modulus, J_1 = first stress invariant or bulk stress, ϕ = moisture tension, γ_d = dry unit weight, μ_r = resilient Poisson's ratio

(3) M_r and J_1 are calculated at r=0 and center of respective layer

(4) S.T. refers to Sibley till (never frozen except at noted).

(5) τ_{oct} = octahedral shear stress (kPa)

(6) Negative normal stresses and strains are compressive.

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